MANAGEMENT OF A *PTEROCARPUS ANGOLENSIS* POPULATION UNDER THE INFLUENCE OF FIRE AND LAND USE

F. Patrick Graz

November 1996

Thesis presented in fulfilment of the requirements for the degree of Master of Science at the University of Stellenbosch.

Dr. H.J. van Hensbergen

Declaration

I the undersigned hereby declare that the work contained in this thesis is my own original work and has not previously in its entirety or in part been submitted at any university for a degree.

Date: 25/11/96

F. P. Graz

ABSTRACT

Pterocarpus angolensis is Namibia's most important indigenous timber species. The species is currently heavily exploited and more goal directed management needs to be implemented to ensure its continued survival in the country. However, the local knowledge of the species as well as its environment is very limited, making the development of management strategies very difficult.

This study reviews the available literature on *P. angolensis* and the dry savanna woodlands in which the species occurs. The applicability of this literature to Namibian conditions is investigated through a vegetation study. The literature and results of the field study are then used to compile a model of the savanna system, with a link to a *P. angolensis* model.

The model is used to investigate the behaviour of the savanna system and a *P. angolensis* population under a variety of conditions, and provides the basis on which management recommendations are formulated.

UITTREKSEL

Pterocarpus angolensis is Namibië se belangrikste inheemse saaghoutsoort. Die boomsoort word tans intensief benut, en meer doelgerigte bestuur is nodig om sy voortbestaan in die land te verseker. Die huidige stand van kennis betreffende die soort is beperk, wat die ontwikkeling van bestuurs-strategie bemoeilik.

Hierdie studie hersien die beskikbare literatuur betreffende *P. angolensis* en die droe savanna bose waarin die soort voorkom. Die toepaslikheid van hierdie literatuur vir Namibiese omstandighede word met behulp van 'n plantegroei-opname getoets. Die uitslae van die opname, sowel as die literatuur word dan gebruik om 'n model van die savanna sisteem te ontwikkel, met 'n verband na 'n *P. angolensis* model.

Die model word gebruik om die gedrag van die savanna system en 'n *P. angolensis* bevolking onder invloed van 'n aantal invloede te ondersoek, en vorm die basis vir die formulering van aanbevelings vir bestuur.

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1. INTRODUCTION

The structure of the dry savanna woodlands in northern Namibia is progressing towards open savanna with scattered trees (see Photo 1). The forestry authorities regard this trend as a degradation of the woodlands, and attempts are to be made to reverse this trend.

Photo 1. A distinct gap is visible between the canopy and the grass layer. Although some woody plants occur in between the herbaceous layer, they are burnt back to ground level at each fire (F.P. Graz, July 1993)

One of the leading causes of the change in vegetation structure is the high incidence of fire in the woodland areas. Although fire is known to play an important role in the maintenance of the savanna ecosystem the current frequency is assumed to have a detrimental effect. These assumptions are derived from findings from neighbouring countries (e.g. Trapnell 1959, Knoop 1982), as well as from studies within Namibia (Geldenhuys 1977).

Further impact on the woodland comes from the use of woodland resources by the indigenous population, and the formal and informal timber industry. Important resources include firewood, land for grazing and shifting cultivation, building material, veld foods, sawtimber and other uses.

Kiaat *(Pterocarpus angolensis)* is the most important indigenous timber species in Namibia. Its occurrence is limited to the dry savanna woodlands in the northern and north eastern parts of the country. The available information on the species indicates that its population structure and development is strongly influenced by periodic disturbances of the woodlands through land clearing and/or fire (Vermeulen 1990).

Further investigation into the ecology and distribution of the species in the Namibian context is necessary before goal directed management and silviculture can be implemented.

The general framework for environmental conservation and conservation based forestry is provided by the constitution of Namibia and the National Forestry Policy (1992, unpublished).

For the purposes of this study the objectives given by the two documents are interpreted and summarised as follows:

> To ensure the long-term survival of the dry savanna woodlands by promoting the evolution of a resilient vegetation structure and species composition which will permit the exploitation of woodland resources.

More specifically, this study concerns the structural development of the dry savanna woodlands, with special emphasis on the management of P. *angolensis*. The objectives are as follows:

- To consolidate and evaluate existing information on *Pterocarpus angolensis*

- To describe the most important ecological processes which influence the dynamics of the dry savanna woodlands with particular consideration of *P. angolensis*.

- To investigate the effect of fire and land use on the status and development of *P. angolensis* in the study area.

- To evaluate available information with regard to the exploitation of *P. angolensis*.

Due to these multiple objectives, the study is divided into six parts. The first part provides background information of the conditions experienced in Namibia in general and the study area in particular. The second part reviews the available literature on the species *P.angolensis*, while the third reviews the literature on savanna and savanna woodlands in which the species is found.

Part four provides a detailed description of the study area and stratifies it for a field study, using basic remote sensing techniques. The field work is intended to determine the relevance of the literature to the Namibian context and is reported on in part five.

The final part describes the development and use of a model to investigate the application of the literature study and field results. Although the six parts are treated separately, they are none-the-less closely interlinked.

1.1 Purpose of the Field Enumeration

To determine the applicability of the published literature to the conditions experienced in Namibia a field survey was required to provide the following specific information:

1. A comparison of the vegetation in areas under different grazing and fire regimes.

The variables that were considered were:

- The woody vegetation density
- Differences in growth forms of woody species.
- The density of grasses and other herbaceous vegetation.

2. A comparison of the population structure of *P. angolensis* in relation to differences in the general vegetation.

The variables selected were:

- The diameter distribution of the species. While an age class distribution would have been preferable, the difficulty in aging *P. angolensis* made the establishment of such a distribution impractical.
- The height distribution of the species.

3. Soil condition

The soil variables that were assessed are:

- physical parameters.
- chemical quantities.

1.2 The Modelling Approach

The limited literature available shows that there are few research results for *P. angolensis* in Namibia, despite the importance of the species for local economies. Ecological aspects in particular seems to have been neglected. In view of the current exploitation of the dry savanna woodlands, traditional resource use and human population growth such information will become more and more significant in the future, if the species is to persist.

Research on the ecology of *P. angolensis* will, however, require long term studies since the species goes through an extended suffrutex stage (Vermeulen 1990) and may eventually reach an age of over 100 years. It is therefore essential that all available information is processed and evaluated intensively to maximise its use and to indicate further knowledge and research requirements.

The model constructed for this study is a tool to facilitate further understanding of the current information (Starfield and Bleloch, 1986, and von Gadow and van Hensbergen, 1987).

PART 1. DESCRIPTION OF THE STUDY AREA

2. CRITERIA FOR THE SELECTION OF A STUDY AREA

In order to be relevant to the *P. angolensis* industry in Namibia the study area needed to fulfil the following criteria:

- The conditions prevailing in the study area should be representative of the majority of savanna woodland areas of Namibia. These conditions specifically relate to: -
  - soil,
  - rainfall,
  - fire history and
  - agricultural land use practices

- To minimise the cost of the study the amount of available information needed to be as high as possible, and

- The area needed to be readily accessible.

Three regions were considered in terms of these criteria. A short evaluation of these alternatives is provided in Appendix 1.

3. DESCRIPTION OF THE STUDY AREA

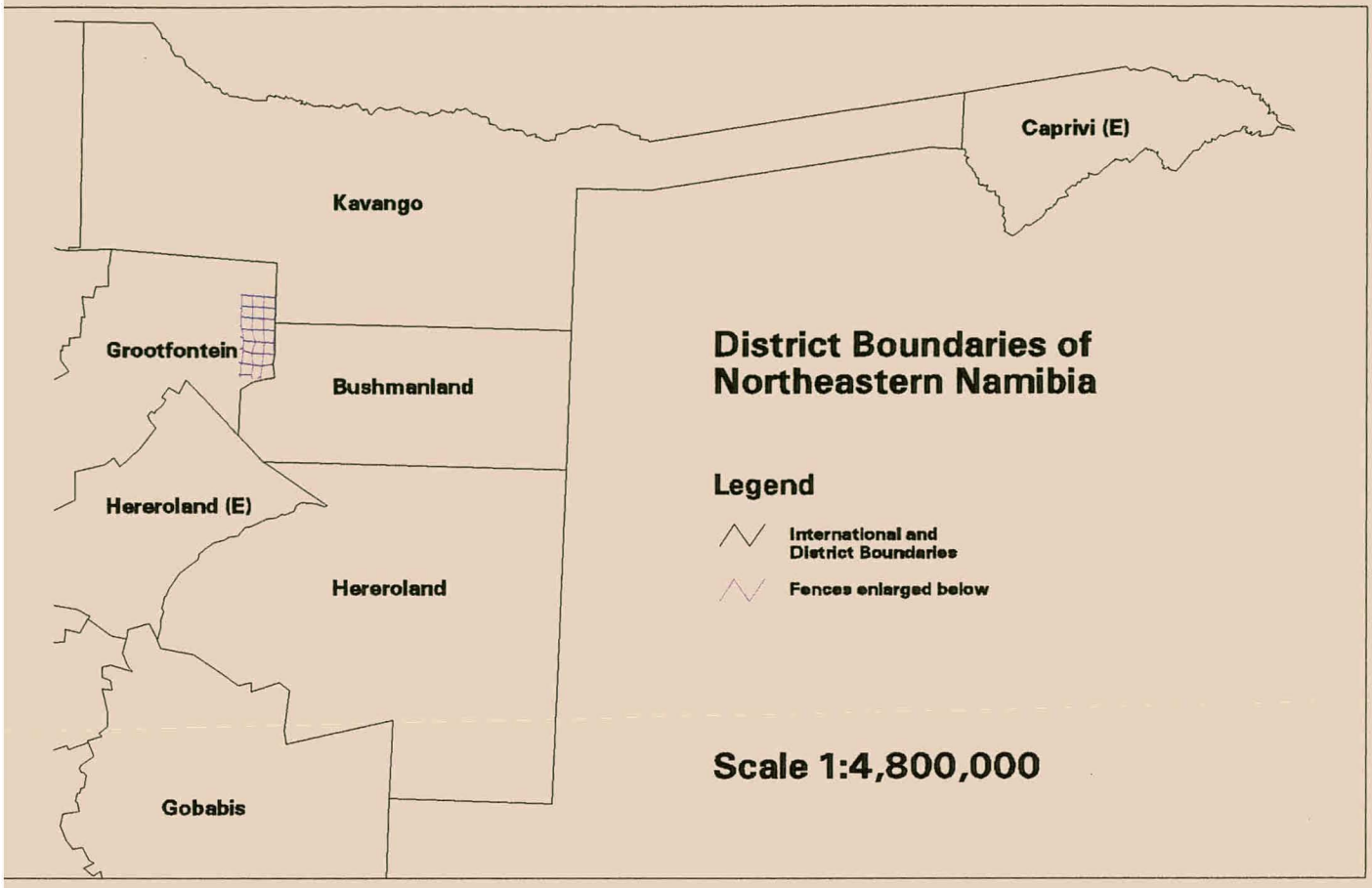
3.1 Location

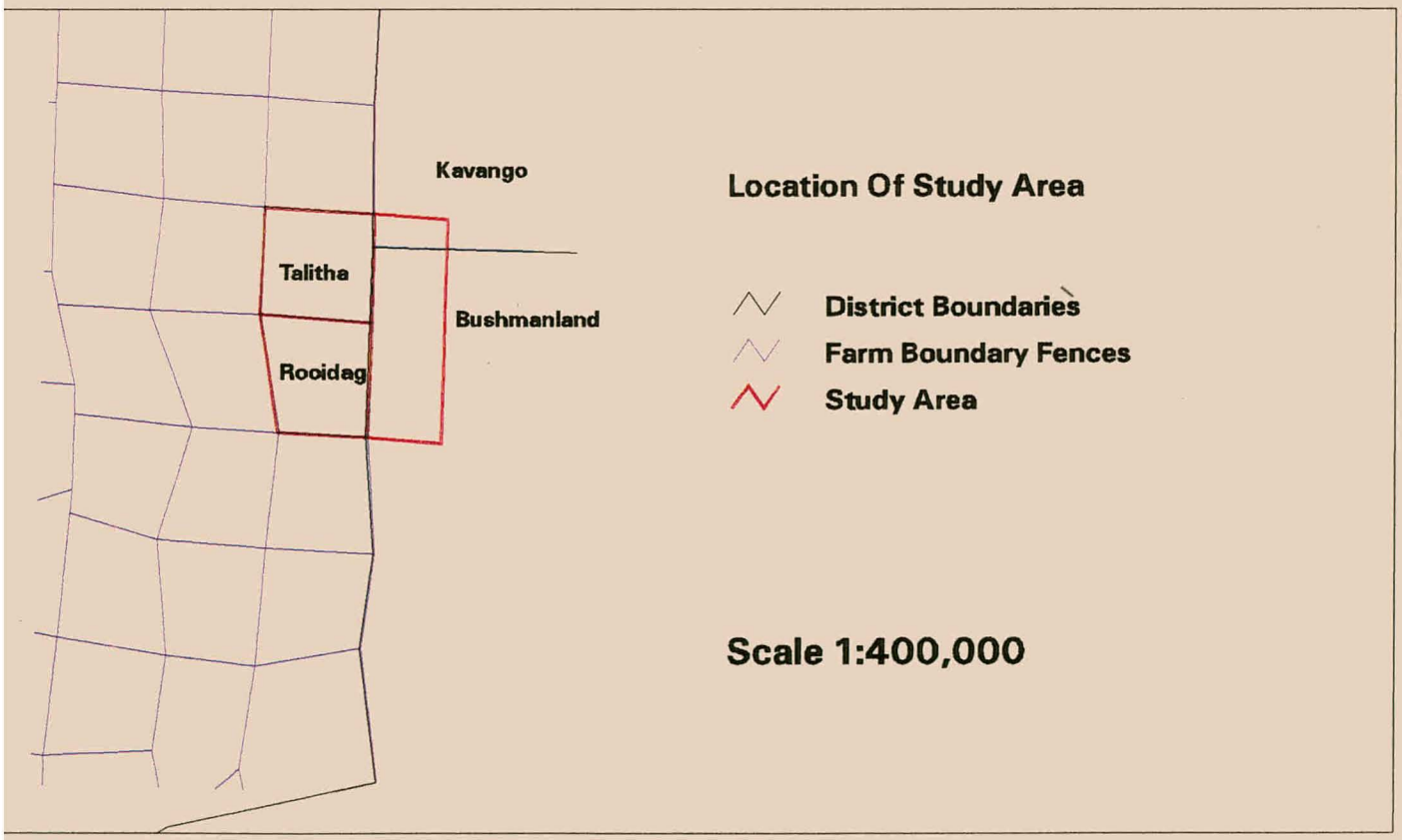
The area selected for the study is located approximately between 19°17'E, 19°5'S and 19°15'E, 19°17'S, and falls within the dry woodlands described by Giess (1971). It includes the farms Rooidag (1001) and Talitha (1006) in the eastern sections of the Grootfontein magisterial district, and an adjoining section in the area formerly known as Bushmanland. Map 1. shows the location of the area in north eastern Namibia.

3.2 Climate

The climate over the southern African sub-region is dominated by two high pressure systems off the west and east coasts of the region; the Atlantic High and Indian Ocean High respectively. During the summer months the two pressure systems are situated further south than during winter, with the centre of the Indian Ocean High well out to sea (Van Heerden and Hurry 1987).

The Atlantic High leads to a flow of air from the ocean onto land. Since this airflow moves only a short distance over cold (Benguela Current) water it picks up little moisture, and gives rise to little or no precipitation (Van Heerden and Hurry 1987).





Map 1. Location of Study Area

N

Projection: UTM 33

The major source of moisture is the Indian Ocean, east of the sub-continent. Air movement caused by a pressure gradient between the Indian Ocean high and low pressure systems inland, cause moisture to be transported to the western part of the sub-region. Inland rainfall is of convective origin, accentuated by the diurnal heating cycle. Rainfall therefore occurs mostly in the late afternoon and early evening in the summer months and increases from east to west (Tyson 1986).

3.3 Weather Patterns Over The Study Area

3.3.1 Precipitation

Rainfall in Namibia occurs as scattered showers during the summer months (FAO 1981). Much of this precipitation occurs in the form of thunder-showers (*pers. obs.*). During winter, on the other hand, no rain is recorded (FAO 1981).

According to Amakali (1992) the study area lies in a region which receives between 450mm and 500mm of rain per year.

Rainfall is highly variable, although this variability cannot be quantified as there is insufficient data available (Amakali 1992). Chivell and Mostert (1991) had previously attempted to provide a formal statement on rainfall variability. The two authors used the records of 28 rainfall stations in the Karst area (Tsumeb-Otavi-Grootfontein) to assess precipitation.

They considered that rainfall cycles with a fourteen year period occur but were unable to confirm such cycles statistically (Chivell and Mostert 1991). Although the area covered by Chivell and Mostert is some 100km south-west of the study area it represents the nearest weather stations with long-term, formal records.

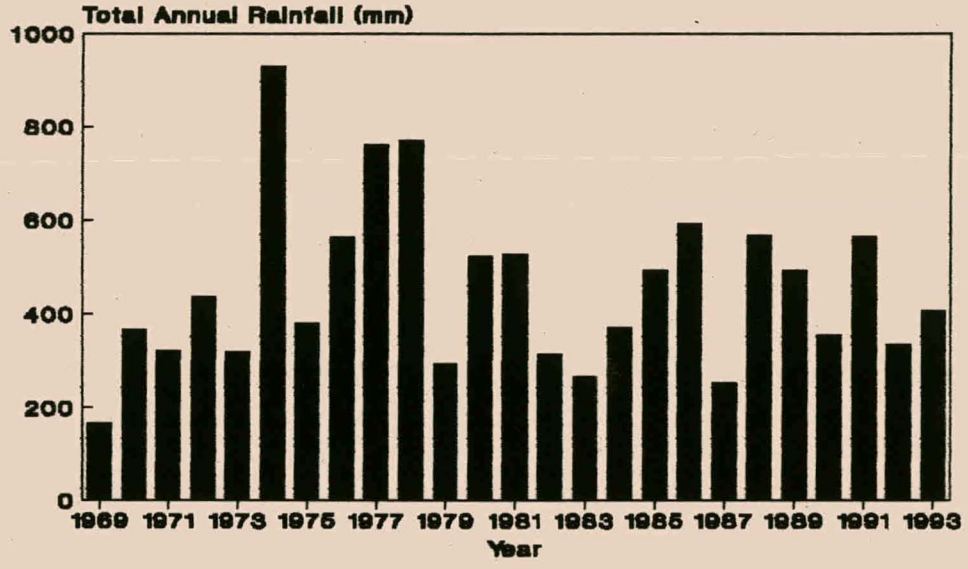


Figure 1. The annual rainfall on farm Rooidag since 1967 (Based on recordings from a non-standard, plastic rain-gauge).

The annual variation of precipitation of the farm Rooidag is summarised in Figure 1. Figure 2 depicts the monthly distribution of rain on Rooidag, as averaged over the last 25 years. Although these records were not standardized with the requirements of the Namibian Weather Bureau, the figures

nevertheless provide important indications of rainfall patterns.

Figure 2 shows that the annual rainfall in the study area occurs in a single wet season from late October to mid March. No rain has been recorded in June, July or August. Rainfall recorded during May and September represents less than one percent of the annual total (calculated from the monthly means).

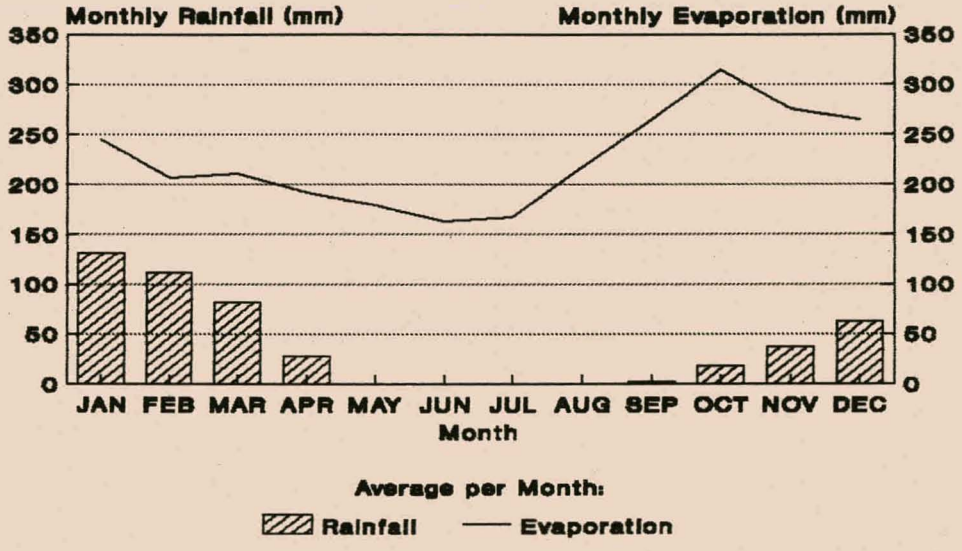


Figure 2. The monthly distribution of rainfall on Farm Rooidag, and the estimated pan-evaporation after Crerar and Church (1988).

3.3.2 Evaporation

According to Crerar and Church (1988) potential evaporation over Namibia lies between 2600mm and 3800mm per year. In the

study area, however, rates vary between 2600mm and 2800mm per year (Namibia Ground Water Development Consultants 1991). A long term mean evaporation of 3120mm has been recorded in Grootfontein, the weather station closest to the study area (Crerar and Church 1988).

Like annual precipitation, evaporation is probably variable between years, and between seasons. Insufficient data is available, however, to analyse evaporation statistically.

For practical purposes Namibia has been divided into four evaporation zones. These are arbitrary and changes in evaporation rates are gradual (Crerar and Church 1988). The study area falls on the boundary between zones A and B, with mean monthly evaporation rates as indicated in Table 1.

Table 1. Mean monthly evaporation rates of Zones A and B, as percentage of total evaporation of between 2600 to 2800mm. (After Crerar and Church 1988) See also Figure A.

	Month											
Zone	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
A	7.8	7.4	8.3	7.6	7.2	6.2	7.0	8.6	10.1	12.0	9.5	8.3
B	10.3	7.9	7.3	6.6	6.1	5.9	5.4	7.5	9.5	11.3	10.9	11.3
Mean*	9.1	7.6	7.8	7.1	6.6	6.1	6.2	8.1	9.8	11.7	10.2	8.8

* Interpolated Mean for the study area

It is clear from Figure 2 that evaporation far exceeds precipitation and that plants therefore need to cope with a severe water deficit. Water availability must therefore be a primary constraint in plant establishment and development. This is especially so since the soils which support the vegetation under study have a low water holding potential (Department Water Affairs 1971).

3.3.3 Relative Humidity

Records from Grootfontein Airport (the weather station closest to the study area) indicate that there is a large daily and annual fluctuation in the relative humidity.

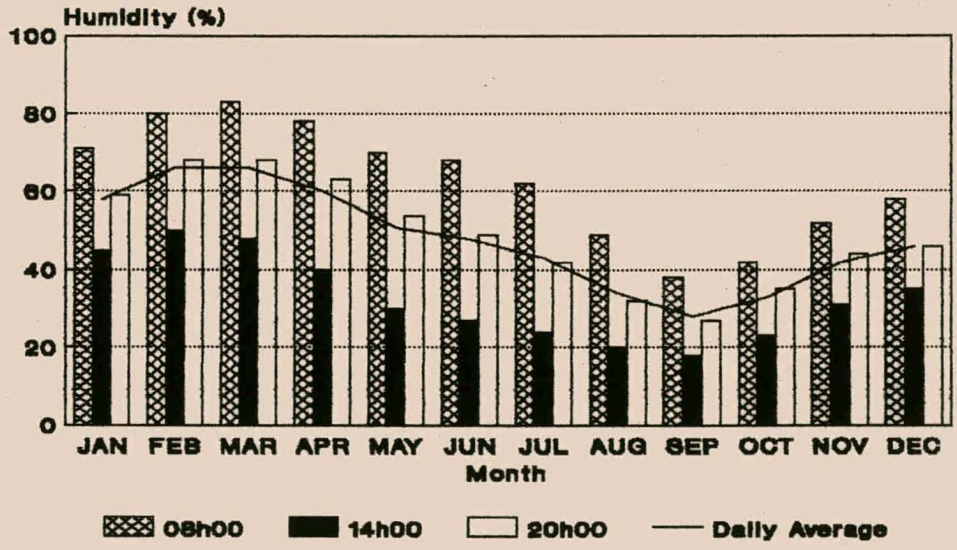


Figure 3. The average daily relative humidity at Grootfontein at 08h00, 14h00 and 20h00, the overall daily average.

Figure 3 shows the daily average relative humidity at 08h00, 14h00 and 20h00, as well as the overall daily average; all values are summarised from the available records dating back to 1968 (Namibia Weather Bureau 1995). It is evident that the relative humidity reaches its minimum during September, just before the next rains may be expected (See Figure 2).

3.3.4 Wind

The orientation of the linear dunes which characterise the study area (see later) were formed by prevailing easterly winds (Department Water Affairs 1971). The wind data which could be obtained for the Grootfontein Airport did not indicate conclusively wether or not this pattern had changed (Weather Bureau of Namibia).

A high frequency of cyclones ('dust devils') occurs in the dry season. It is evident that they distribute wind borne seed; probably over considerable distances (*pers. obs.*).

3.3.5 Temperature

The closest weather station which has recorded temperature data regularly in the past is at the Grootfontein Airport (Namibia Weather Bureau 1995). A summary of these recordings is provided in Table 2.

Table 2 shows that the highest daily temperatures are found from September to January, and the lowest between May and

August. Maximum difference between daily maximum and minimum temperatures occur from May to September.

Table 2. Average daily temperatures and the temperature extremes measured at Grootfontein Airport. The averages are based on records from 1968 to 1985 (Namibia Weather Bureau 1995).

Month	Average Daily Maximum	Average Daily Minimum	Absolute Maximum	Absolute Minimum
JAN	30.3	17.9	38.3	11.6
FEB	29.0	17.2	38.7	11.1
MAR	28.5	15.9	36.1	5.9
APR	27.7	13.0	34.8	5.6
MAY	25.6	8.1	32.7	-1.7
JUN	23.2	4.9	28.1	-0.5
JUL	23.6	4.4	29.5	-3.4
AUG	26.9	7.4	33.4	-6.0
SEP	30.7	11.9	35.4	-0.4
OCT	32.0	15.7	36.8	5.4
NOV	31.7	17.1	37.5	7.6
DEC	32.0	17.6	37.4	10.5

3.4 Soils and Ground Water

The study area is characterised by large, stable linear dunes (seif dunes) orientated east-west. These were formed under arid conditions by easterly prevailing winds, and were colonised and stabilized by vegetation in a wetter period, possibly under climatic conditions similar to those prevailing today (Department of Water Affairs 1971).

The sand of the dune ridges has a poor water holding capacity and nutrient status, and therefore has low agricultural potential. Nevertheless these soils usually support taller trees (Department of Water Affairs 1971) than the soils between the dune ridges (streets).

The street soils have a heavier texture, are comparatively shallow and approach the level of the underlying calcrete (Department of Water Affairs 1971). These soils are therefore characterized by a different species composition.

In some areas very low dunes occur, which give rise to a vegetation made up of the species found on the dune ridges and in the streets. These low dunes have soils similar to those of the higher dune ridges and are therefore referred to as 'broken dunes' (afr. "gebroke duin") by the local farmers.

Figure 4, provides an indication of the relationship between dune ridges, streets and broken dunes.

A ground water survey carried out on behalf of the Department of Water Affairs in 1991 indicated that the water table in the study area is around 100m to 120m below the surface, although some of the farmers in the area maintain that their boreholes are upto 300m deep.

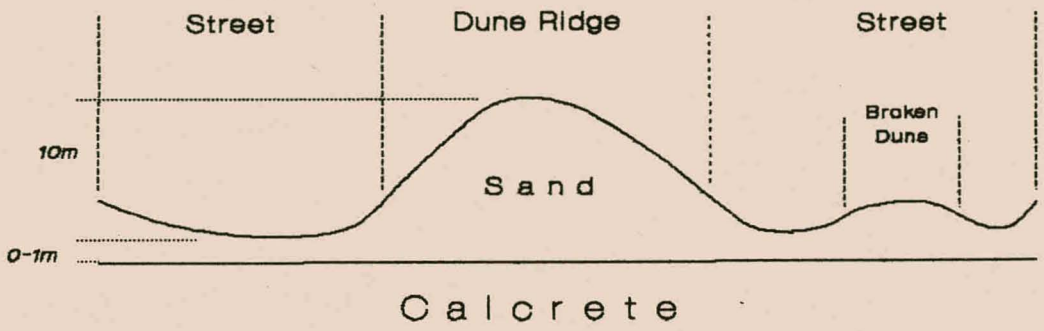


Figure 4. The relationship between dune ridges, broken dunes and streets in the study area. (See later in text).

3.5 Fire

No documentation concerning the incidence of fire in the study area could be found. During discussions with farmers it became evident, however, that the farms had burnt infrequently since the 1960's, when they had been established (Vermaak *pers. com.*).

On the other hand, the area to the east of the farms, in the communal area, was burnt almost annually. While no records on the causes of fire are available, it is assumed that most are

caused by man, either intentionally or as a result of carelessness.

More accurate estimates of fire frequency, distribution or fire season may be determined with the aid of NOAA satellite images. The costs involved in doing so are, however, beyond the means of this project.

3.6 Farming Practices

The farms in the study area were established in the 1960's (Vermaak *pers. com.*), and have since been used for cattle farming. Also, some areas in the streets are suitable for cultivation.

The farmers have fenced off the street vegetation from the dune ridges, and utilize these areas at different times of the year. The dune ridge camps are often infested with *Dichapetalum cymosum*, a poisonous plant which sprouts much earlier than the remaining vegetation and attracts the domestic cattle. The farmers therefore avoid use of these camps in the early growing season, since cattle losses have been quite substantial in the past.

The grazing pressure on the two farm in the study area differ considerably, with grazing markedly heavier on Rooidag.

PART 2. THE SPECIES *Pterocarpus. angolensis*

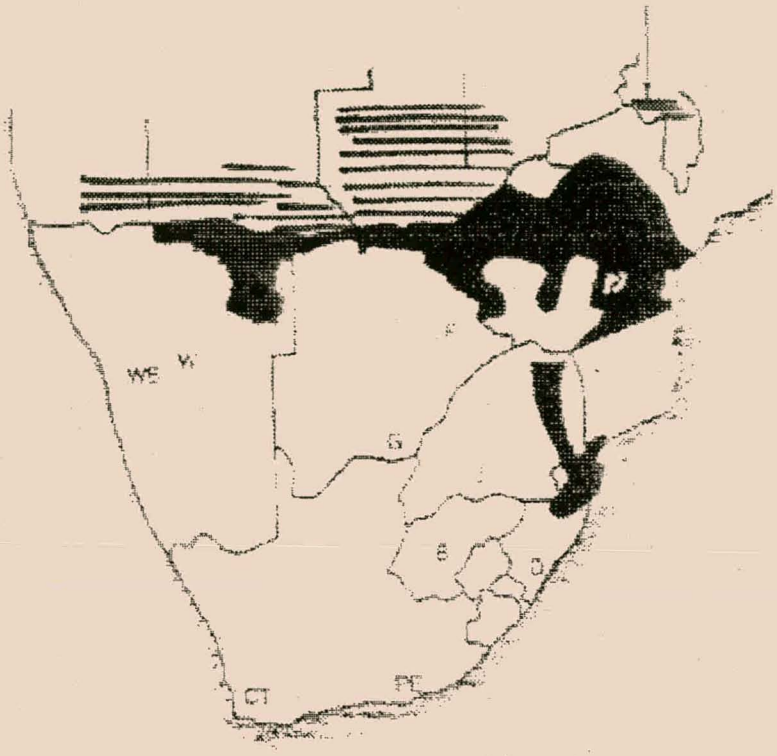
Photo 2. A *Pterocarpus angolensis* tree in dune vegetation on Farm Talitha (F.P. Graz, October 1994).

4. DISTRIBUTION

Pterocarpus angolensis is a Leguminous tree (von Breitenbach 1973) which belongs to a genus comprised of about 100 species (Dyer 1975). Four of these species occur in the northern and eastern parts of southern Africa.

The countries in which *P. angolensis* is found include Zambia (Trapnell 1959), Malawi (P. Hardcastle *pers. com.*), Mozambique, Tanzania (Groome *et al.* 1957b), Angola, Namibia, Botswana,

South Africa, Zimbabwe (Coates Palgrave 1983) and Swaziland (Dyer 1975).



Map 2. The distribution of *P. angolensis* (adapted from Coates Palgrave 1983). Shaded areas indicate unconfirmed reports from foresters who had worked in those areas (*pers. com.*).

5. DESCRIPTION

The leaves of the tree are imparipinnate (Dyer 1975) and are arranged alternately on branchlets (Coates Palgrave 1983), with young leaves densely, silky-pubescent (von Breitenbach 1973). Minute glands are often found on the underside of leaflets (Coates Palgrave 1983).

Leaf-flush is cued by the first rains (Childes 1989, Vermeulen 1990), and Coates Palgrave (1983) and Childes (1989) state that leaves fall early. Although he does not define 'early', Childes presumes that leaf fall commences in response to moisture stress at the start of the dry season.

To enable the tree to flush prior to the first rains food materials produced in March and April are stored (Vermeulen 1990) rather than used for growth.

Flowers are orange to yellow and occur in large, branched sprays (10 to 20cm long) from August to December (Coates Palgrave 1983). According to Childes (1989) flowering commences before leaf flush, and is markedly synchronised; probably induced by temperature and photoperiod.

6. SITE REQUIREMENTS AND GROWING CONDITIONS

6.1 Soil

Within its distribution range *P. angolensis* occurs mostly on deep sands, with the biggest trees on well-drained soils with a sandy or loamy texture (Vermeulen 1990).

Personal observations and discussions with local forestry staff indicate, that the species was able to establish itself on the slightly heavier soils of a dry river bed in Bushmanland, Namibia. None of the plants observed had developed beyond the

suffrutex seedling / stage (see later in text) and assumptions about long term survival cannot be made.

6.2 Water

The species occurs in areas which are characterised by well defined wet and dry seasons. Rainfall may be as low as 500mm / annum (Vermeulen 1990, Groome *et al.* 1957b), (although precipitation in the study area is somewhat less) and a water table of around 70m (Vermeulen 1990).

The soil conditions favoured by the species together with the rooting strategy described by von Breitenbach (1973) and Vermeulen (1990) indicate that the species' water requirements are met by precipitation rather than a permanent subterranean water supply. This brings the tree into competition for water with the remaining vegetation. Under conditions of exceptional competition for ephemeral water resources, however, *P. angolensis* is not successful (von Breitenbach 1973).

6.3 Light

According to Groome *et al.* (1957b) and Vermeulen (1990) *P.angolensis* is a light demanding species. Although it may persist in moderate shade it is likely to stagnate. On the other hand, other authors consider that *P. angolensis* may survive as a suffrutex in shade conditions for a number of years and is able to form a permanent shoot once conditions improve (Boaler and Schiwale 1966)

6.4 Frost

While high temperature may cause *P. angolensis* to produce leaves early, frost may have detrimental effects. Low temperatures appear to affect younger plants in particular, causing them to die-back. Older growth does not seem to be affected as severely, although periodic damage may occur (Groome *et al.* 1957b).

7. REPRODUCTION AND DEVELOPMENT

7.1 Fruit and Seed

Flowers are pollinated by insects (Childes 1989), to produce one to six pods from a raceme. Each pod is covered with spiny bristles and surrounded by an orbicular wing. The entire fruit is between 50-150mm in diameter (Vermeulen 1990), and carried on a stalk about 10mm in length. (See Figure 5)

The wing provides the fruit with an excellent gliding ability; dust-devils may carry them up to 3km (Groome *et al.* 1957a). Most fruit, however, do not travel more than about 30m from the parent tree (Vermeulen 1990), so that the heaviest fruit deposits occur around the trees with the largest crops (von Breitenbach 1973).

Generally, pods are detached from the parent tree in the late dry season or early wet season (von Breitenbach 1973) by wind

(Vermeulen 1990), but may also be beaten down by rain (Groome *et al.* 1957b).

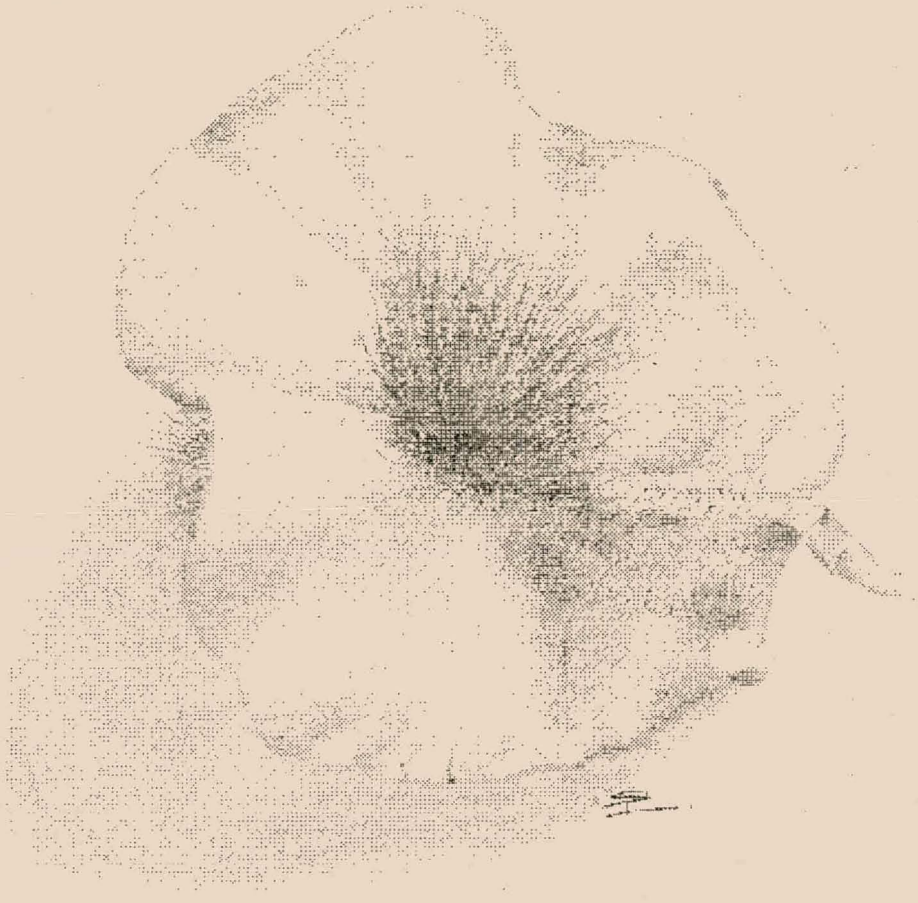


Figure 5. The fruit of *Pterocarpus angolensis*; actual size (by S. Irlich, 1995).

Fire is known to remove the wing and hairs and to bring the fruit into contact with the ground, if they have been lodged in brush or grass (van Daalen 1991).

Trees only produce fruit after 20 years (Vermeulen 1990). This delay is possibly influenced by the suffrutex stage through which the species develops before it produces its first permanent shoot. It is, however, not clear if Vermeulen

calculates the age of the tree from time of germination of the seed, or as the age of the permanent shoot.

The size of fruit crops is correlated with the degree of openness of the stand. Trees established on recently abandoned cultivated lands bear particularly heavy crops (Vermeulen 1990). (Von Breitenbach (1973) considers 200-400 fruit per tree to be a heavy crop.) The large crops produced in open areas not only emphasize the light requirements of the species, but also have other important ecological implications. These will become evident later in the text.

7.2 Seed Release and Germination

Pod opening appears to be induced by repeated wetting and drying in the later part of the rainy season, or after commencement of the following wet season (von Breitenbach 1973). Groome *et al.* (1957b) also suggest that the moisture is conserved below pods detached by rain which attract termites who would then crack the hull. Vermeulen (1990) assumes, however, that termites remove only the wing and bristles but do not open the fruit.

Von Breitenbach's observations indicate that the pods of *P. angolensis* do not open before the fire season commences in contrast to other woodland species. This provides the species with a competitive advantage over others which are prone to fire damage.

P. angolensis rarely produces more than one seed per pod, although this may change with location (Vermeulen 1990).

Germination of the seed is epigeal (Vermeulen 1990) and is estimated to require two weeks (Geldenhuys 1975) immediately after the pod has opened (Vermeulen 1990).

Fire has been found to enhance germination under natural conditions (Geldenhuys 1975, van Daalen 1991), although this influence is dependent on the intensity of the fire. Very intense fires have been found to reduce the viability of the seed, whereas 'cool' fires have very little influence on germination at all (van Daalen 1991).

Nursery observations indicate that *P. angolensis* germinates best without shade (Groome *et al.* 1957b). Together with the observations reported by von Breitenbach (1973) and Vermeulen (1990) - regarding the relationship between fruit crop and stand density - the heavy fruit crops produced in open areas would provide the species with a greater chance to persist in open stands.

Competition for water will also be less between woody plants in open stands once the seedlings are established. Initially however, competition with the herbaceous vegetation is likely to be high with a concomitant mortality.

Once the pod is detached from the parent tree the seed rapidly loses its viability (Groome *et al.* 1957a, Vermeulen 1990). Although Geldenhuys (1975) estimates the limit of viability of the seed at 1 to 2 years, Hilbert (*pers. com.*) has successfully germinated five year old seed. He did not indicate how the seed was stored.

7.3 Establishment

Vermeulen (1990) notes that seedling establishment is closely related to the amount of rain. Seedlings are, however, subject to a high degree of mortality which may be caused by a number of factors. These include fire, nutrient deficiencies, damage by animals, and intra- and interspecific competition (Vermeulen 1990). The available literature indicates that such competition is primarily for water. This is further supported by Groome *et al.* (1957b) who state that drought is a cause of mortality. This in turn corroborates Vermeulen's report regarding seedling establishment in relation to rainfall.

In the establishment phase the seedling develops a tap root of between 45 and 90cm within the first growing season (von Breitenbach 1973). This taproot then thickens to a depth of 60cm and then tapers off rapidly.

Seedlings quickly enter a suffrutex stage which usually continues for a number of years. During this period the plant

produces shoots which reach a height of between one and two meters each growing season. These die back in the subsequent dry season to a depth of about 2-3cm below the surface (von Breitenbach 1973), thus effectively protecting the growth points against dry season fires.

The period of annual die-back continues for a period of around 10 years. During this time the root-system develops to an extent where it may collect sufficient water and nutrients to support a permanent shoot through the dry season (von Breitenbach 1973, Vermeulen 1990).

Finally, open stands are generally associated with a dense herbaceous cover. These in turn give rise to a higher likelihood of fire (Heikkila *et al.* 1993). In this instance the higher fire tolerance of *P. angolensis*, as well as its suffruticous behaviour provides the species with a competitive advantage over other woody species.

7.4 Development

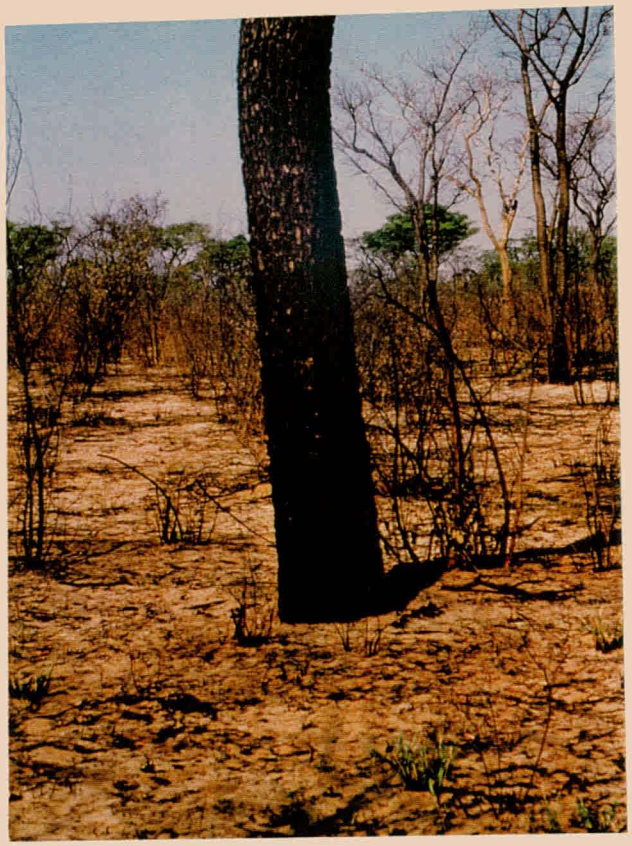
Growth rate and ultimate tree size are strongly genetically controlled (Vermeulen 1990), although development is otherwise highly dependent on environmental factors. Final tree height is for instance directly related to the productivity of the site (Vermeulen 1990).

Generally, a tree will reach its full crown diameter in the third or fourth decade (von Breitenbach 1973) It is, however, not clear if von Breitenbach calculates from year of germination or from the year in which the permanent shoot was formed. No clear relationship between age and crown diameter has been established thus far (Vermeulen 1990).

The lateral roots of a fully grown canopy tree will spread over an area greater than the reach of the crown, to a diameter of 15 to 20m, in the upper 30 to 60cm of the soil. Numerous 'sinkers' are sent down to a depth of about 2m (Vermeulen 1990).

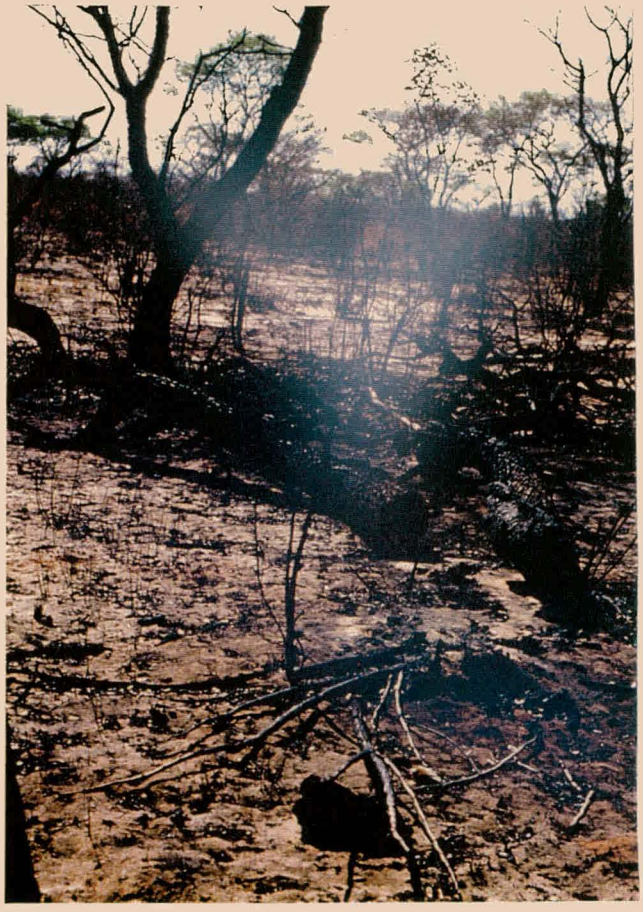
8. MORTALITY

While the plant is in the seedling stage it is most prone to damage by animals. Large mammals browse on the young leaves and wild pigs have been known to dig up entire plants to reach the fleshy tap-root (von Breitenbach 1973). Van Daalen (1991) also indicates that grazing pressure can have detrimental effects on seedling survival. It is not clear from his text how this is caused, i.e. through physical damage or indirect causes. Later, trees may be damaged by elephant which are reported to chew the bark (Groome *et al.* 1957b).



3.

4.



Photos 3, 4 and 5.

Progressive damage to the bole of *P. angolensis* trees, as a result of frequent fires

5.

Very high fire frequencies are also known to cause the development and enlargement of fire lesions on the trunk of trees, causing them to collapse. Photos 3, 4 and 5 illustrate the approximate sequence.

9. FIRE TOLERANCE

Apart from the stimulating effect that fire has on seed germination, fire plays an important part in the maintenance of the *P. angolensis* population as a whole.

While the strategy of annual die-back and re-growth may protect the seedling from fire damage, annual burning retards the development of plants from the suffrutex to sapling stage (Vermeulen 1990). Only once it has reached the sapling stage may the species benefit from its higher fire resistance.

This is somewhat in contrast to the description of von Breitenbach, who considers the suffruticous behaviour to be a protection mechanism guarding against fire damage. It must, however, be considered that the shoots remain standing after they have died off, thus providing a fire bridge to the below-ground parts.

The saplings themselves may tolerate fire temperatures of between 400°C and 450°C, whereas most other woodland species die at lower temperatures. The removal of competitors will

allow saplings to obtain greater benefit from the subsequent ash-bed effect (Vermeulen 1990, von Breitenbach 1973).

Geldenhuys (1992) observed a high stem density of smaller classes of *P. angolensis* (as well as *Burkea africana*) in Kavango, northern Namibia. This he attributed to the high frequency of moderate fires in the region.

The superior fire tolerance also assists the species during the colonisation of open areas. The development of herbaceous vegetation is favoured in such areas, leading to a correspondingly higher fire frequency and intensity. The large fruit crops that von Breitenbach and Vermeulen associate with trees in such areas, also increase the likelihood of recruitment.

On the other hand, fire seems to be the main factor which prevents the re-establishment of felled areas from coppice regrowth (Vermeulen 1990). The thinning of the canopy as a result of felling may lead to an increase in the herbaceous vegetation with a subsequent increase in fire intensity. These speculations require verification, however.

Vermeulen (1990) reports that shoot growth is enhanced if the herbaceous vegetation is removed by fire. In view of the discussions in Part 3 of this study, this effect is considered to be the result of a number of factors or combinations

thereof. These include reduced competition for water as a direct result of the removal of the herbaceous layer (after Walker and Noy-Meir 1982) or changes in nutrient status of the soil such as found by Knoop (1982).

10. MANAGEMENT CONSIDERATIONS

Vermeulen's review of the species provides a summary of management strategies which have been proposed by various authors. It is not evident if any of these strategies have been implemented or tested successfully. The silvicultural treatments presented by Vermeulen generally refer to countries with higher rainfall.

While *P. angolensis* is reputed to have a life expectancy of 90-100 years (Vermeulen 1990), the difficulty of determining the age of the trees presents one of the most important limitations to the development of management programmes. According to Van Daalen *et al.* (1992) the tree forms false growth rings which limit the usefulness of ring counts. Additionally, a large proportion of the trees in Namibia are hollow (*pers. obs.*).

Observations of diameter-class distributions in sample plots in Tanzania and Mozambique indicate that stands are probably even aged (Groome *et al.* 1957b). Considering the site requirements of *P. angolensis*, as well as the difficulty with which the species is able to establish itself under other trees this is probable.

The (re-) establishment of felled areas provides further difficulties for active management. Vermeulen (1990) reports that propagation of seedlings or cuttings in nurseries is extremely difficult, and survival rates of seedlings which have been planted out are low. He speculates that this is probably due to the development requirements of the root system. Vermeulen does not indicate any association with mycorrhiza. Such a relationship does exist, however, according to the National Tree Seed Programme (NTSP), Tanzania (NTSP 1995)

Photo 6. Coppicing *P. angolensis* stump 4 years after felling. (F.P. Graz, July 1993)

Coppicing may be an alternative to regenerate the species in the field, since *P. angolensis* is a persistent coppicer especially in the seedling and establishment stages. However, this regeneration strategy is not reliable enough for timber production unless fire control is implemented (Groome *et al.* 1957b).

The management proposals presented by Vermeulen (1990) indicate that management should concentrate on coppice and suffrutex management. Such management could include fire protection, protection from animal damage, or transplanting suffrutex plants in the field.

In addition, conditions which provide the species with a means to seed out in the field should be encouraged. Such management may be required to concentrate on fire control, but would also need to consider the thinning or clearing of woodland areas. Land clearing would reduce competition and benefit the establishment of seedlings (Erkkila and Siiskonen 1992)).

11. MANAGEMENT OF *Pterocarpus angolensis* IN NAMIBIA

Due to the limited knowledge of *P. angolensis* in Namibia none of the silvicultural practices cited by Vermeulen (1990) have been implemented. Also, the forestry sector has had a very low priority in the past, and only a few resources were made available. Research on the development of coppice shoots in the Bushmanland area had been initiated in the late 1980's but

was terminated in 1994 when resources were withdrawn (Hilbert pers com).

There is no current information on the growing stock of *P. angolensis* in Namibia, although some estimates have been made in the past. In anticipation of a more detailed forest inventory the vegetation in the north of the country is currently being mapped using satellite image maps. However, during discussion with mapping team members it became evident that the designation of species was not very accurate in the first phase of the project, which covered the most important woodland areas.

Despite the lack of knowledge about the current status of the species, exploitation is continuing while the inventory is in progress.

Currently a total of about 7000m^3 of roundwood is harvested annually for sawtimber in Caprivi, Kavango and Bushmanland. On average recovery to sawn wood is about 40% (v.d. Berg *pers. com.* 1992, Orr *pers. com.* 1992). Further quantities are harvested for carving and carpentry for the tourist industry. The illegal exploitation cannot be quantified, but is assumed to be high.

Harvesting quotas for the saw mills in Katima Mulilo, Rundu and in Bushmanland are given in terms of a harvestible area and an

estimate of standing volume. Volume estimates based on a reconnaissance survey in some parts of Bushmanland in 1989 indicate a periodic allowable cut of 600m³ per 100km² (Hilbert *pers. com.*). However, the distribution of *P. angolensis* is patchy (*pers. obs.*) and quotas must be adjusted accordingly. Hilbert (*pers. com.*) suggests a rotation of 50 years.

Felling quotas for the informal sector are granted in numbers of trees, and volumes are not recorded.

Trees are felled selectively. Selection is based on diameter rather than age. This system was first implemented in the 1960's (Hilbert *pers. com.*). In accordance with the specified procedures only trees with a diameter exceeding 45cm may be cut. Where multi-stemmed trees are encountered, fellers are required to leave at least half of the stems standing.

It is not clear on what criteria the minimum diameter was based (Hilbert *pers. com.*). The ease with which the system may be implemented and controlled has made it very attractive.

However, this selection system may result in the equivalent of local clear-felling, as was seen in parts of Bushmanland. This is consistent with the findings of von Breitenbach (1973) in Caprivi and with regard to site dependent growth rate and ultimate size of trees, and the diameter distributions reported by Groome *et al.* (1957b) .

PART 3. AN OVERVIEW OF SAVANNA WOODLAND ECOLOGY

12. FACTORS WHICH DETERMINE VEGETATION STRUCTURE

12.1 Soil Moisture Balance

Eagleson and Segarra (1985) assume that the soil moisture balance is the single most important factor which controls the formation of the savanna system. Factors such as fire, herbivory and human influences are only regarded as modifiers.

Their approach to the ecology of the savanna ecosystem is based on the competition for soil water between members of a species, between species, and between growth forms. The discussions of Walker and Noy-Meir (1982), with respect to the competition between woody and herbaceous vegetation, are of particular importance.

Walker and Noy-Meir divide savanna soils into two layers on the basis of the vegetation component they support; the upper layer primarily supports the herbaceous and the lower layer the woody vegetation .

They state, however, that this subdivision is oversimplified since the woody vegetation also uses the upper soil layer and some grass species send their roots into the lower. Nevertheless the division of the soil into layers is a useful conceptual tool in understanding the function of the savanna system.

While Walker and Noy-Meir are referring to *Acacia* savanna their simplification is supported by Knoop (1982) and Knoop and Walker (1985) for broad-leaved *Burkea africana / Ochna pulchra* savanna.

From the descriptions by Walker and Noy-Meir (1982), Knoop (1982) and Knoop and Walker (1985) it is evident that the rooting strategy of individual vegetation components (species or growth form) determines their ability to survive within a given plant community. The significance of individual components or species vary, however, as environmental conditions favour one or another rooting strategy. The effects of modifying factors such as herbivory or fire must also be borne in mind.

Yeaton (1988) and Smith and Grant (1986) considered that shallow root systems provide an individual with access to soil moisture from light rains. Although these authors were referring primarily to trees it may be assumed that grasses will have a similar advantage under such circumstances.

Goldstein and Sarmiento (1987) on the other hand, point out that the soil will dry out in the dry season from the top downwards. Shallow rooted plants must therefore be able to cope with widely varying soil moisture conditions. Plants which develop deeper-reaching root systems may continue to grow

longer into the dry season, provided that water is available in the lower-lying soil layers.

The woody vegetation would therefore depend primarily on heavier or more frequent showers which allow water to penetrate to the lower soil layer. This does not mean that woody plants show an immediate increase in growth rate when rainfall is high; the reaction is delayed (Walker *et al.* 1981) by the time needed for water to reach the appropriate soil depth.

The ability of grasses to compete for water in the upper soil layer has particularly strong implications for the establishment of woody seedlings (Skarpe 1990) which must develop a large root system in order to obtain sufficient water to survive several months of dry season (Trapnell 1959). High herbaceous vegetation densities would therefore be expected to retard the establishment and development of the woody component by restricting its access to water.

Under conditions of high potential evapo-transpiration, as prevalent in the study area, photosynthesis and transpiration may continue at high rates until the plant available soil water is depleted. (Below this point the rates of both decline (Scholes 1990)).

In view of the implications which soil moisture has for the development of the vegetation, the actual effect will be

modified by those factors which influence the soil moisture balance, either directly or indirectly.

Soil properties such as texture and water holding capacity must therefore be regarded as important factors, although the latter is strongly influenced by the former (Weber and Stoney 1986). Organic matter content also increases the soil water holding capacity, but this factor is considered separately.

A higher water loss to evaporation must be expected from heavy textured soils, as a result of higher run-off and evaporation (Scholes 1990) due to retarded infiltration. Sandy soils, on the other hand, allow rapid penetration of water into the lower soil layers (Knoop 1982).

Geldenhuys (1977), for instance, suggests that thickets can not develop near Rundu (Northern Namibia) as water is unable to percolate to lower-lying soils because of poor drainage.

Additionally, Scott and Schulze (1992) found that fire liberates hydrophobic substances which may form a water repellent band in the soil, effectively reducing infiltration. If such substances are distiled on to individual soil particles the water binding capacity of such soil is reduced.

12.2 Climate

The effect of climate on the dry savanna woodlands is primarily due to its effect on the soil water balance. Rainfall and the effect of temperature are of particular interest.

The effect of wind is also important during wind-borne dispersal of seed, as well as because of its influence on evapo-transpiration and fire behaviour.

12.2.1 Rainfall

A primary characteristic of rainfall in savanna type systems is its seasonality. Rain falls in one or more well defined wet season followed by an equally well defined dry season (Goldstein and Sarmiento 1987).

As stated previously, precipitation is the most important determinant of soil moisture. Its effect must be considered both in terms of its quantity and its distribution over time.

The depth to which water infiltrates into the soil is influenced by the amount of water which remains after evaporation from the soil surface. Knoop (1982) found for instance that in years of above average rainfall, wetting occurred down to bed-rock (> 4m), while water filtered to a depth of less than 130cm during a drier wet season, even in the absence of a herbaceous layer.

A shallow root system therefore allows a plant access to soil moisture even from lighter rains. According to the model of Walker and Noy-Meir (1982) this would apply primarily to the herbaceous vegetation component. Lubke (1986) observed that the herbaceous plant cover is more strongly influenced by fluctuating rainfall than are other vegetation components. In addition, O'Connor (1994) found that parameters such as abundance of grass, plant basal area and mortality were more responsive to rainfall variability than to grazing.

According to Knoop and Walker (1985) competition for water between woody and herbaceous vegetation is most severe in years of intermediate rainfall. They maintain that during a dry year, water will be intercepted by the herbaceous plants before it reaches the lower soil layers. On the other hand, in very wet years the herbaceous layer will have comparatively little effect, so that sufficient water becomes available to the woody plants.

Skarpe (1992) suggests that water supply controls the duration of the growth period, while nutrients control the growth rate. Gourlay and Barnes (1994) in turn found a correlation between growth ring width and annual rainfall of the preceding year. A delay in the effect of rain on growth is expected due to the time required for the water to filter to the root zone of woody plants.

In the total absence of a herbaceous layer all water infiltrating the first layer of soil is potentially available to the woody vegetation.

Rainfall also has indirect effects on vegetation development. Siegfried (1981) found in Etosha that seasons of well-above normal rainfall were followed by a relatively high incidence of fires; probably as a result of the higher amount of biomass made available as fuel. The spatial distribution of rain also affects the movement of herbivorous animals, which select areas that have received rain, and avoid those that have not. The effect of herbivory on the savanna vegetation is discussed later.

Few references to the effect of temporal distribution of rain on soil moisture were found. Authors primarily referred to the total amount of rain, or average rainfall when assessing its importance. This is probably as a result of the long observation periods required before a meaningful analysis of temporal distribution of rain can be carried out.

Barbour *et al.* (1987) state that the seasonal distribution of rain determines the amount of water available to the vegetation, and compare the development of different vegetation types in the presence of different rainfall regimes.

The following additional inferences can be made.

Schole's (1990) findings regarding the duration and rate of evapo-transpiration by grasses are of particular importance. Rain will only be of advantage to the woody vegetation if the infiltration rate is greater than the rate of evapo-transpiration of the herbaceous component. Both, short, heavy rains as well as long, light rains should allow moisture penetration to the lower soil layers. It should be noted, however, that short heavy rains are likely to result in a comparatively high run-off and therefore reduced infiltration. This depends on the texture of the soil.

12.2.2 Temperature

The effect of temperature on components of savanna woodlands has received little attention. Only a few indirect references were found.

As reported earlier, Geldenhuys (1977) and Childes (1989) suggest that flowering of *P. angolensis* and *B. africana* is stimulated by temperature.

While the influence of temperature on evapo-transpiration must be considered, as well as its effect on fire danger (Heikkilae *et al.* 1993) further review of the effect of temperature was found unnecessary.

12.2.3 Wind

No reference was found concerning the significance of wind in savanna ecosystems.

The effect of wind on transpiration rates and evaporation have previously been discussed by Barbour *et al.* (1987) in general terms.

Wind plays an important role in the distribution of seed. Woodland trees which have their seed distributed by wind include *Pterocarpus angolensis* (Vermeulen 1990), various *Combretum* species (Carr 1988) and *Terminalia sericea* (Yeaton 1988). Personal observations indicate that *Burkea africana* seed is also carried by wind.

In addition, the effect of wind on fire-behaviour must be kept in mind. High wind velocity results in a higher fire danger as well as higher fire intensity.

12.3 Competition

12.3.1 Light

The overall importance of light for the growth and development of plants has been discussed elsewhere and will not be discussed here in detail. (See Grime and Jarvis (1975) for discussions on the effects of light on the germination of seed, growth and development.)

The quantity of light within the woodland environment plays an important part in the development of individual plants as well as in the species composition and structure of the woodland as a whole. According to van der Meulen and Werger (1984) the availability of light at ground level in woodlands is primarily determined by the tree layer, which intercepts the incoming sunlight. They found that the amount of light transmitted through a tree canopy decreases with an increase in the number of layers through which the light passes.

The amount of light determines which species are able to establish themselves. Yeaton (1988) found, for instance, that *Burkea africana* is able to establish itself under other trees, while *Terminalia sericea* is apparently suppressed by shading. P. *angolensis* also requires light, although individual plants may persist in moderate shade (Groome *et al.* 1957b). The three species occur within the study area.

Light also plays a significant role in the development of the herbaceous layer. Lawton (1978) and Skarpe (1991) have shown that grasses grow more slowly if they are shaded by trees. This has implications for the incidence and severity of fire within the woodland, as well as suitability of the woodland areas for grazing.

In addition, the suppression of the herbaceous vegetation will increase the amount of water reaching the lower soil layers

which will favour the development of deeper rooted (woody) plants.

12.3.2 Nutrients

Knoop (1982) found that woody plant growth was enhanced if the herbaceous layer was removed. Although it may be expected that this would be as a result of a change in soil water availability, Knoop presumed that it was a result of increased nitrate levels in the soil.

The higher nitrate levels were, however, only observed initially, after the herbaceous vegetation component had been removed. Similarly Ruess (1987) reported increases in nitrogen and phosphorus in the soils of grazed areas.

13. FACTORS WHICH MODIFY VEGETATION STRUCTURE

13.1 General

While soil moisture is the most important determinant of vegetation structure and its development, the effects are modified by a variety of other factors.

Walker (1987) describes the savanna as an event driven system in which rainfall and fire play major roles. In the presence of such influences Walker regards other, modifying factors to be of secondary importance. Hochberg, Menaut and Gignoux (1994) also recognize that changes in fire and herbivory regimes cause changes in vegetation structure.

Walker (1987) assumes that the importance of events and modifiers are related to the spatial and temporal scales at which the system is viewed. Although the system may seem highly variable over a period of only a few years, it may show stability over a longer period.

13.2 Land Use

13.2.1 Herbivory

While this text distinguishes between the impact of herbivory and fire on the development of the savanna woodlands, their effects are combined under natural conditions (Siegfried 1981).

The term herbivory is used here to mean the reduction or removal of the above ground biomass of herbaceous plant material by either domestic or wild herbivores.

According to Walker *et al.* (1981) and Ruess (1987) light grazing may stimulate grass growth, and lead to a higher grass biomass. Such increases are due to the induction of tiller formation of perennial grasses.

Heavier grazing, on the other hand, causes a decrease in grass production, or even, under very heavy grazing pressure, the death of individual plants. The threshold between light and heavy grazing is not specified by Walker *et al.* (1981) or Ruess (1987)

Grazing pressure needs to be viewed in terms of the ability of grass plants to recover from the damage caused by grazing. Under conditions which support fast growth plants may withstand a higher pressure than they would otherwise.

A reduction of herbaceous cover as a result of heavy grazing may cause a shift to greater densities of woody plants (Knoop and Walker 1985) due to higher water infiltration.

Wild species and domestic livestock can be expected to have different effects on the vegetation because of differences in the timing, intensity and duration of grazing.

Livestock, unlike wild herbivores, is often provided with supplementary resources, such as water, and usually protected from natural mortality. Also, the movement of domestic animals is restricted for management purposes by barriers or herders, thus preventing migration in response to vegetation change.

According to Skarpe (1992) perennial grass plants may be affected adversely by the continuous presence of grazing animals. (Skarpe did not indicate clearly at what grazing pressure continuous grazing would have adverse effects.)

The effect of grazing is especially important in an environment with variable rainfall. Temporary droughts may change

perennial vegetation into one dominated by ephemerals. Excessive grazing may slow or prevent the redevelopment of the perennial vegetation component once rainfall increases (Skarpe 1992). Similar observations were recorded by Pandy and Singh (1992) who found grazing intensity to be more important than rainfall in determining the variability of live shoot biomass. On the other hand, grazing reduces plant transpiration and thus conserves soil water (Ruess 1987).

From the findings of Skarpe (1992) and Ruess (1987) it is evident that the woody plant component will benefit by grazing during a dry year, since more water is made available (after Ruess) and the perennial herbaceous vegetation component is disadvantaged (after Skarpe).

Van Daalen *et al.* (1992) report that grazing pressure may have a detrimental influence on the survival of *P. angolensis* seedlings. The authors did not, however, substantiate this. The suffrutex plants may be partially defoliated through browsing or subject to other physical damage. In addition von Breitenbach (1973) reports that bushpigs may dig out the seedlings because of the fleshy tap root.

A further effect of grazing is the accelerated cycling of nutrients. Ruess (1987) provides an extensive review of this field. He reports that the distribution of dung or urine by wild animals as well as domestic stock (Ruess cites sheep)

causes nutrient transfer between habitats. Domestic herbivores cause similar cycling of nutrients; in particular they cause the concentration of nutrients in overnight kraals and at watering points, and a corresponding reduction of nutrients in day camps.1

13.2.2 Cultivation

The effect of cultivation on the development of the savanna woodland vegetation is discussed under section 16 "Plant Succession".

It must, however, be noted that the vegetation considered in this study is usually found on sandy soils which are reportedly unsuitable for cultivation (Department of Water Affairs, 1971).

13.3 Fire

13.3.1 Fire Frequency

Fire is an important modifier of woodland vegetation structure. Although some fires are still caused naturally, most are now a result of the actions of man (Lawton 1978, Siegfried 1981, Frost and Robertson 1987) either purposely or accidentally.

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1. In the study area further differences in the effect of grazing by domestic animals and wild herbivores are caused through the effect of the grazing season. *Dichapetalum cymosum* (Gifblaar) is a poisonous plant which occurs mostly at the foot of sand dunes (de Sousa, unpublished). During the late dry season this plant appears as the only green vegetation on the dune ridges and attracts domestic cattle, causing heavy stock losses. Farmers therefore prefer to use the dune camps during the rainy season, when the plant is less conspicuous.

Savannas have been subject to human use for at least 2000 years, induced fire and wood collection having important impacts (Norton and Walker 1985).

The effect of fire manifests itself not only in the removal of organic material but also through the heat given off. While the former has implications for the frequency with which fires may occur and their intensity, the latter influences the structure of the affected plant population.

Removal of the organic material and its mulching effect affects the soil moisture balance in the top soil. Also important, however, is the killing of smaller plants and their partial consumption during the fire. According to Trollope (1982) the effect of frequency of burning is dependent on the degree to which plants are able to recover in the intervals between fires. This effect is modified by fire intensity.

Fire affects different species and size classes in different ways, and plants may die as their fire tolerance is overcome. The remaining, more resistant plants, may survive and develop aggregations of fire resistant species (Skarpe 1991, Hochberg *et al.* 1994). It follows that size class specific mortality may result in groups of plants which are of similar age.

According to Rutherford (1981) many studies have found an increase in the number of basal shoots with an increase in fire

frequency. These ensure the survival of the individual plant if the above ground parts are killed or badly injured by fire. Coppicing behaviour has been observed on a number of tree species which occur in the study area (e.g. *Pterocarpus angolensis*, *Burkea africana*, *Combretum zeyheri*), but the shoots are often more susceptible to damage by fire than the original stem. Where high frequencies of fire are experienced even coppicing is not sufficient to ensure the survival of individuals.

Younger trees are most prone to fire damage. Rutherford (1975) found, for instance, that even infrequent fires may kill *Burkea africana* trees up to 4m in height, while larger trees are not as seriously effected. Vermeulen (1990) found that *P. angolensis* seedlings and suffrutexes are more easily damaged by fire than are saplings

Mortality of larger trees may be caused by fire lesions which develop on their trunks (Trapnell 1959) and increase in size at each burn. This has been observed on *P. angolensis* trees in the study area, although the species is regarded as particularly resistant to fire (Vermeulen 1990, von Breitenbach 1973).

Generally, the absence of fire appears to result in an increase in density of woody plants (Lubke 1986), while the cumulative

effects of annual fires produce an open woodland and finally savanna grassland (Malaisse *et al.* 1975).

The frequency at which fires occur is largely dependent on the available fuel, or rather the rate at which fuel is able to accumulate between fires. Siegfried (1981) found in Etosha that seasons of well-above normal rainfall were followed by a relatively high incidence of fires, probably as a result of a greater quantity of available fuel, especially grass fuel.

If an area is protected against fire or is subject to a lower fire frequency, dead organic material is able to build up (Mitchell and Freeman 1993). When a fire does eventually occur in such areas the accumulated litter will often result in greater damage (Trapnell 1959, Geldenhuys 1977).

13.3.2 Fire Intensity

Fire intensity is defined by Trollope (1981) as the rate at which heat energy is released during a fire, and is significantly correlated with the rate of spread of the fire. The faster the rate of spread, the higher the intensity. The size of the fuel involved also plays a significant role. Due to their greater surface area per unit volume, small fuels will produce a higher fire intensity than will larger fuels (Heikkila *et al.* 1993).

The effect of fire on vegetation is greatly dependent on the intensity of a fire (Trollope 1982), with more plants being killed by more intense burns (Rutherford 1981).

Damage by fire is less pronounced in aggregated stands than in scattered individuals. This is as a result of the reduced development of the herbaceous vegetation (Skarpe 1991, Lawton 1978), caused by a lack of light. Fire intensity may also be reduced through grazing (Skarpe 1992), which reduces the load of smaller fuels.

As indicated previously, prolonged absence of grazing and fire will result in a build-up of fuel. This causes a more intense burn when fire eventually does occur. Fire intensity is also dependent on the types of fuel which have been able to accumulate (Trollope 1982).2

13.3.3 Fire Season

According to Frost and Robertson (1987) the incidence of fire caused by lightning is highest at the start of the wet season. On the other hand, most fires in the last few thousand years probably occurred as a result of the activities of man (Barbour

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2 With regard to the study area, a less luxuriant grass cover has developed on the dune ridges than in the streets, due to the poor water holding capacity and nutrient status of the dune soils (Department of Water Affairs, 1971). In addition, the vegetation in the western parts of the study area is subject to grazing though only for parts of the year. This retards the build up of small fuels and makes the vegetation less subject to intense burns. (For a description of the dune vegetation refer to "Preliminary mapping of Vegetation")

et al. 1987). Irrespective of the causes, however, fires occur primarily in the dry season or early wet season, since fuel moisture is otherwise too high to support a burn.

The effect of fire season as discussed here refers to the timing of a burn within the dry season. An early burn would therefore imply a fire occurring shortly after the beginning of the dry season.

Trapnell's (1959) evaluation of the Ndola plots in Zambia showed that continuous early burning permitted the formation of clumps of regeneration. These clumps shade out most of the grass to form self protected islands, as the reduced amount of grass fuels support fewer, less intense fires.

Repeated late fires, on the other hand, open up the woodland, since the more intense fires cause heavier losses among smaller trees and shrubs, and may even damage canopy trees (Trapnell 1959). The resulting increase in openness of stands will benefit the development of the herbaceous layer, thus increasing the likelihood and intensity of fires. This cumulative effect may eventually lead to the total destruction of the woodland (Trapnell 1959).3

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3 As stated previously, the camps falling within the dune vegetation are utilized primarily during the wet season because of the occurrence of Gifblaar. This will reduce the amount of water removed from the top-soil by the herbaceous plant component, to the benefit of the woody plants (Rues 1987).

The effect of fire season is largely manifested in a difference in fire intensity, late burns are usually hotter than those which occur earlier in the dry season (Rutherford 1981). Early burns therefore cause less damage to tree growth and regeneration than do late burns. At such time the woody plants are dormant (Lawton 1978), and mostly senescent leaves and other dry materials are removed.

At the end of the dry season, however, coppice-shoots and newly emerged leaves will be damaged by fire. New coppice growth may be burnt back to ground level and even the crowns of canopy trees may be damaged (Lawton 1978), if there is sufficient fuel.

To promote the formation of closed woodlands Trapnell (1959), Geldenhuys (1977) and Chidomayo (1988) propose that management burns are carried out as early as possible after the end of the rainy season.

According to Trollope (1982) the removal of the vegetation by fire in the dry season may stimulate the herbaceous layer to grow, leading to increased evapo-transpiration. Such growth of the herbaceous vegetation weakens the individual plants, since they use root reserves which would otherwise have been available at the beginning of the moist growing season.

Geldenhuys (1977) reported that regeneration of *P. angolensis* is significantly better if the undergrowth is burnt during the dry season, resulting in reduced competition for soil moisture. He did not indicate if timing of the burn within the dry season was important.

13.4 Fire and Soils

Given the importance of the soil moisture balance on the development of vegetation the influence of fire on soil properties is considered separately.

In his assessment of the Caprivi, von Breitenbach (1968) considers soil condition to be a direct or indirect product of fire and agricultural practices. Since the study area is only marginally subject to cultivation, the effects of pastoral farming and fire are relevant.

The effect of fire on soil can be divided into two categories. Effects can be either physical, such as the reduction in soil organic matter, or chemical, such as changes in nutrient levels. It should be noted that changes in the soil chemistry may cause changes in the physical properties of the soil, for instance by modifying the ability of soil particles to bind water.

The changes in physical properties which are of direct importance are those which have direct or indirect bearing on

the soil moisture balance. According to Trollope (1982) and von Breitenbach (1968) frequent burning results in reduced water infiltration, possibly as a result of soil compaction (von Breitenbach 1968, Trapnell *et al.* 1976). Although none of the above authors explain this phenomenon, Frost and Robertson (1987) report that loose particles may block pores between soil aggregates.

A further effect of fire is the reduction in organic matter (Malaisse *et al.* 1992), which will cause a decrease in the water holding capacity of the soil, as well as an increase in evaporation (Trollope 1982). Additionally, the stability of soil aggregates may be reduced (Frost and Robertson 1987).

Harrington and Ross (1974) reported increases in some soil chemicals. They found a marked increase in calcium and phosphorous and a higher pH. Effects of annual burning treatments on the soil chemistry at Ndola (Zambia) were most marked for soil pH and readily extracted Phosphorus. Increases were greatest in the late burnt plots of the series (Trapnell *et al.* 1976). Skarpe (1992) reports reduced nitrogen and sulphur levels as a result of frequent and intense fires.

Trapnell *et al.* (1976) interpret this effect of fire in terms of the vegetation structure, since different plants give rise to different fuel compositions. The higher pH levels are caused by the ash remaining after fire.

Higher soil pH has important implications for the uptake of water by plants. The increased ph lowers the osmotic potential of water and subsequently makes water-uptake more difficult (Grobelaar *et al.* 1979).

In general, however, the concentration of plant available nutrients in the soil solution is increased after they are released by fire. This increase is especially noticeable within the first month, and primarily affects the upper soil layers (Frost and Robertson 1987) and is therefore largely to the advantage of the herbaceous vegetation component. Young regeneration of woody species will also benefit.

An additional effect of fire is the release of hydrophobic substances from plant litter. These are translocated down into the soil where they condense onto the soil particles, and may cause the formation of a water repellent layer in the soil (Scott and Schulze 1992). Such hydrophobic layers may even form on the surfaces of sandy soils (Frost and Robertson 1987) and affect the soil water balance.

14. A SIMPLIFICATION OF THE SAVANNA SYSTEM

The discussions of the determining and modifying factors, as provided above, give rise to the development of the following simplified schematic representation of the savanna system in figure 6.

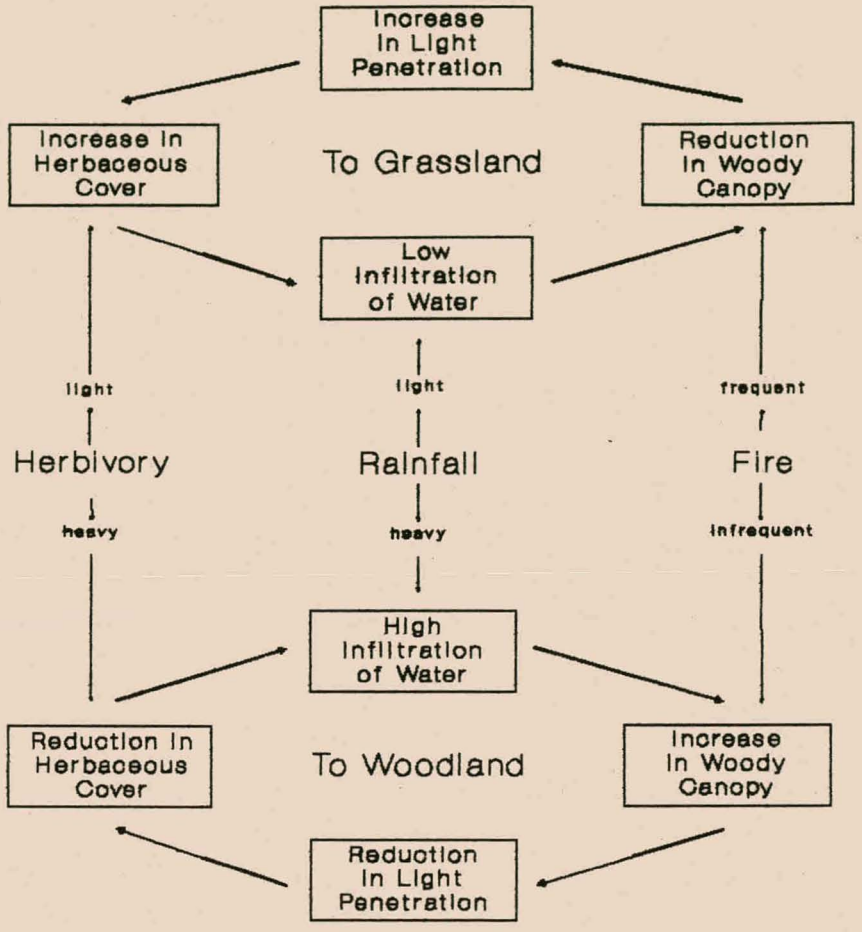

Figure 6. A simplification of the savanna system.

The figure reflects the interaction between the woody and herbaceous vegetation in the system. According to the diagram two cycles are possible, i.e. one where the herbaceous vegetation is promoted, and the other which promotes the woody vegetation. Rainfall, herbivory, and fire are seen as the factors that determine the cycle which will be favoured.

15. ADAPTATIONS

Only the most important adaptations for plant survival within the dry savanna woodlands will be dealt with below. Also, although the importance of wild animals is recognised, their effect will only be discussed in terms of the adaptations of plants which have developed under their influence.

15.1 Regenerative Strategies

Childes (1989) supports the hypothesis that phenological events for plants which occur on Kalahari Sand are correlated with the severity of environmental stresses (cues). Childes indicated that leaf flush and flowering of some tree species, including *B. africana* and *Terminalia sericea*, are synchronised with rainfall. Others seem to be cued by photoperiod, such as *Baikiaea plurijuga*. He discusses the advantages which various tree species have as a result of their response to various stimuli, such as attracting pollinators or minimizing seed predation.

Most of the species which occur in the dune type vegetation, including *Pterocarpus angolensis* (Groome *et al.* 1957a), *Combretum zeyheri* (Carr 1988), *Terminalia sericea* (Yeaton, 1988, Childes 1989) or *Burkea africana* (personal observations, Childes 1989) seem to specialize in dispersal through wind-borne fruit. The fruit of these species have either developed one or more wings (such as *P. angolensis* (Vermeulen, 1990) and *Combretum* species (Carr, 1988)), or produce flat fruit

(*Terminalia* species, *B. africana* (Coats Palgrave, 1983)) to provide them with gliding ability.

On the other hand, many legumes, especially members of the genus *Acacia*, specialize in mammalian dispersal, and have adapted their fruit and seed accordingly (van der Pijl, 1982). Adaptations include smooth, hard seeds (which are resistant to damage during mastication) and nutritious fruit. 4

The difference in dispersal agent may be a result of the poorer regeneration of grasses evident on the dune ridges. This would lead to a lower grazing potential and therefore reduced animal (herbivore) presence under natural conditions. Chances for animal dispersal of seed would therefore be low. Further investigations in this regard are, however, beyond the scope of this study.

Many of the woody species which occur in the dry savanna woodland system are able to produce coppice shoots when the above ground parts are damaged or killed. Observations in this regard were made by various authors for a variety of species. These include *Burkea africana* (Walker *et al.* 1986), *Combretum zeyheri* (Carr 1988) and *Pterocarpus angolensis* (Groome *et al.* 1957b). *Terminalia sericea, Dichrostachys cinerea* and *Acacia*

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4 These adaptations seem to be most prevalent in the street type vegetation in the study area (See 'Preliminary Mapping of Vegetation Types' for a description of the dune and street vegetation types.)

mellifera also coppice vigorously (*pers. obs.*). While coppicing may be induced by the removal of the dominant stem, as seems to be the case with *D. cinerea*, *B. africana* or *P. angolensis*, Carr (1988) speculates that *C. zeyheri* produces shoots in response to unusually favourable weather conditions.

Trapnell (1959) on the other hand indicates that coppicing may be a response to nutritional factors in the early stages of establishment and root development, when seedlings are subject to the combined effects of competition and water shortage during the dry season.

Seed dispersal and coppicing are two modes by which species may persist in an area. The two strategies have different genetic implications. Reproduction by seed provides opportunity for genetic diversification, coppicing ensures the persistence of existing genetic material within the area.

15.2 Rooting Strategies

A variety of authors (Smith and Grant 1986, Yeaton 1988, Vermeulen 1990) indicate that various woody species specialize in the absorption of water from specific soil layers. *Terminalia sericea* has the bulk of its roots at 12-23cm below surface (Smith and Grant 1986, Yeaton 1988), *Burkea africana* at 50-60cm while *Pterocarpus angolensis* forms lateral roots at 30 to 60 cm below ground from where numerous "sinkers" are sent to a depth of 2m (Vermeulen 1990).

Furthermore, rooting depth will influence the speed with which a plant responds to rainfall. Childes (1989) reports, for instance, that leaf flushing and flowering of a number of tree species which occur on sand, are cued by the increase in water availability after the first rains. Shallow rooted plants will therefore be able to respond more quickly.

16. PLANT SUCCESSION

In their studies Boaler and Sciwale (1966) recognised a particular sequence of events after cultivation of miombo (*Brachystegia* spp.) woodland areas. Although the two authors worked in an area with a different species composition from the study area, *P. angolensis* reportedly occurs.

Boaler and Sciwale (1966) identified the following successional stages in an open area after cultivation:

> *Pioneer Stage*: Recently abandoned fields have a high production of tall grass. The grass biomass is higher than in untouched miombo and fires are therefore fiercer.
>
> From the literature reviewed under Section I it is evident that *P. angolensis* is more successful in establishing itself in such areas rather than in areas where it must compete with other woody species.

Thicket Stage: Thickets of woody saplings develop in which grass growth is much reduced or non-existent. These thickets reduce fire intensity or may prevent fire from entering such areas at all (Rutherford 1981).

Developing Woodland: Tree densities are reduced as a result of competition between woody plants. This opens out the stand of woody plants and grasses re-invade. Similar observations were made by Skarpe (1992). Fires are likely to become fiercer in response to the higher load of small, herbaceous fuel.

Open Wooded Savanna: Finally, a balance between the woody and herbaceous components is reached where both vegetation components will remain stable.

Apart from the structural changes of the vegetation described by these authors it must be expected that a succession of species occurs. Yeaton (1988) found for instance that *Terminalia sericea* was generally followed by *Burkea africana* in a successional sequence, while *B. africana* can establish itself in open areas.

Species succession in relation to change in vegetation structure is of particular importance. As stated previously *P. angolensis* is suppressed if there is any competition with other woody vegetation for water or light. The ability of *Burkea*

africana to establish itself under other trees makes it a potential competitor with *P. angolensis* for soil moisture.

Tramer (1975) warns that the description of successional stages must be viewed carefully to distinguish between succession and the priorities established by man. These priorities influence management and development which in turn impact on the landscape.

PART 4. STRATIFICATION OF THE STUDY AREA USING REMOTE SENSING

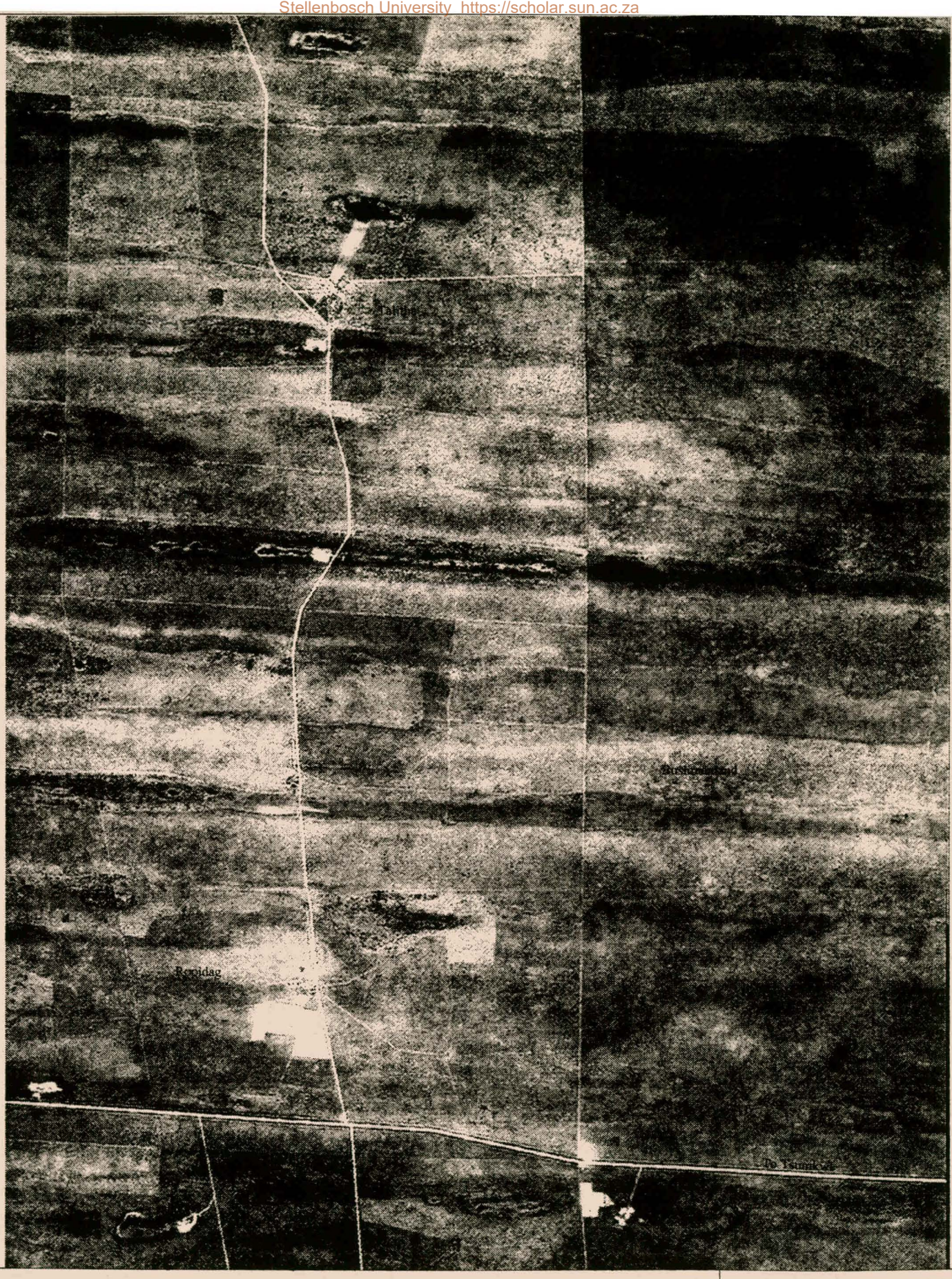
17. MATERIALS AND METHODS

The stratification of the study area was intended to provide a means through which sources of variation could be recognised.

Black and white aerial photographs from 1976, and multiband SPOT XS satellite images from 1992 indicated a marked heterogeneity within the study area. This variability manifested itself through differences in shades of grey on the photographs and differences in colour on the image. Changes in texture, i.e. the degree of 'graininess', on the photos and image implied further variation.

The stratification of the study area was based primarily on previously captured SPOT images. These had been sectioned and printed on photographic paper at a scale of 1:50,000, corresponding to the standard 1:50,000 topographic maps. Details concerning the satellite image are provided in Appendix 3. A black and white extract of the SPOT image is provided in Map 3.

Where there were uncertainties about features on the satellite image map (SIM) reference was made to the digital original. In such cases the area under consideration was enlarged as required, and the acquired information was transferred back to the image map and the transparency (See later). It had been



C33

Extract from SPOT XS image, dated 21 May 1992.

Fosil sand dunes appear in light grey. Dry pans are visible within the inter-dune areas.

Secondary roads are visible as white lines and fence lines as white lines or as a result of abrupt color changes.

See Text

N

Projection: UTM 33

Source: SPOT XS

found impractical to delineate the mapping units on the computer screen using on-screen digitizing techniques.

The interpretation of the SIM's was supported through visits to the area in 1990.

The principles according to which the image was interpreted to obtain the various mapping units are described in Appendix 2.

Despite the advantages of colour provided by the SPOT image, the aerial photographs frequently provided additional information due to their higher ground resolution. This was particularly the case during the mapping of topographic features.

Mapping unit information was captured by fixing a transparent plastic overlay over the SIM. Reference points were determined and marked on the overlay, and the required information traced with a fine, water-resistant marker.

Due to the effect of scale, lines were kept as fine as possible. This was especially important during the preliminary mapping of the vegetation, since the bands of the transitional vegetation type were sometimes below 50m in width (1mm on the SIM) in the field.

The information which had been recorded on the overlays was then digitized using a Calcomp 9100 A0 digitizer and the program ILWIS. The data files were later transferred to ARC/INFO for further processing and printing.

Once the preliminary maps had been compiled the accuracy of the interpretation was verified during a preliminary field survey. Extensive use of the local knowledge of the farmers was made.

The resulting maps accounted for most of the visually identifiable sources of variation. While further differences in colour and texture could be determined they were incorporated in more general mapping units, due to the small areas they represent. (For instance, pans in the streets were not mapped out separately.) These small-scale differences indicate, however, that some variation must be expected within each mapping unit.

17.1 Infrastructure

Infrastructure such as fences, roads and water points have an indirect influence on the development of vegetation since these features affect the movement of domestic and wild animals, and may restrict the spread of fire. The importance of herbivory and fire with regard to vegetation development have been discussed previously (See Sections 13.2 and 13.3 respectively).

Keeping in mind that the study was to provide an indication of vegetation development in relation to grazing pressure the position of water points was noted. It was expected that grazing pressure would be related to distance from water points (Strohbach per com 1994).

The location of most boundary fences and roads could be obtained readily from available 1:50,000 topographic maps and technical drawings provided by the farmers. In addition, the SPOT images provided information on infrastructure that had been developed after the topo-maps had been compiled.

The positions of water points were obtained from the farmers, located in the field, and recorded using a Garmin 100 GPS.

17.2 Identifying Separate Land Use Areas

Although the aerial photos were almost 20 years old, they nevertheless showed clear differences between the communal and commercial farming areas. Marked variations were also visible within each of the two.

The more recent SPOT image exhibited comparable trends, but provided further indications of heterogeneity through variations in colour. Regions displayed on the photos in similar shades of grey in some cases had to be considered dissimilar on the basis of the differences in colour on the images.

During the reconnaissance survey it had become apparent that differences in grazing pressure exist between the farms, with a higher visible impact on Rooidag. Some of the encampments on Talitha showed few signs of domestic grazing, while spoor of wild herbivores were abundant.

17.3 Locating Topographical Features

Keeping in mind the influence of topography on vegetation, it was considered important to locate the position and extent of the most prominent topographical features, namely dune ridges and the areas between them (streets).

Observations made in the area in 1990 and analysis of the contour lines on available 1:50,000 topographic maps indicate that the dune ridges run roughly from west to east. The contours lines on the topographic maps were, however, inadequate to delineate the dune complex accurately, since the contour intervals on the topographic maps were too large.

Since the topographic maps could not be utilised, the SPOT images were referenced. Differences in vegetation reflect differences between dune ridges and the streets between them. This had been found in the field. Such differences had been observed during previous visits to the area, and are related to soil differences (Department of Water Affairs, 1971).

While use was made of an existing (1992) SPOT image no field check had been carried out in the area in the year in which it was obtained. The image had been recorded well into the dry season (May 1992), with very little precipitation in the preceding months.

A visit to the area during the same season in 1993 showed that the bushes in the street vegetation (see below) were still green, whereas the dune vegetation (see below) had already discoloured. The differences in colour on the image were therefore primarily due to changes in soil characteristics.

17.4 Preliminary Identification of Vegetation Types

Since the dune ridge vegetation was assumed to have discoloured at the time that the image was recorded, the ability of the SPOT satellite to differentiate between vegetation types was used to delineate the street vegetation (See Appendix 2 for details). The assignment of the spectral bands (RGB 321) indicated that the vegetation in the streets was still green (indicated as red on the image) whereas the dune vegetation had started to turn brown.

The remaining areas were then classed as 'dune vegetation'.

The interpretation was assessed in the field to determine the accuracy of the classification. Where vegetation changes were

clearly visible locations were marked on the maps by measuring the distance from the nearest fence or along the road.

18. RESULTS

18.1 Infrastructure

Boundary fences were clearly visible on the images as light coloured lines. Abrupt changes in colour and/or texture within the farm boundaries along straight, unbroken lines also indicate the location of fence lines between camps.

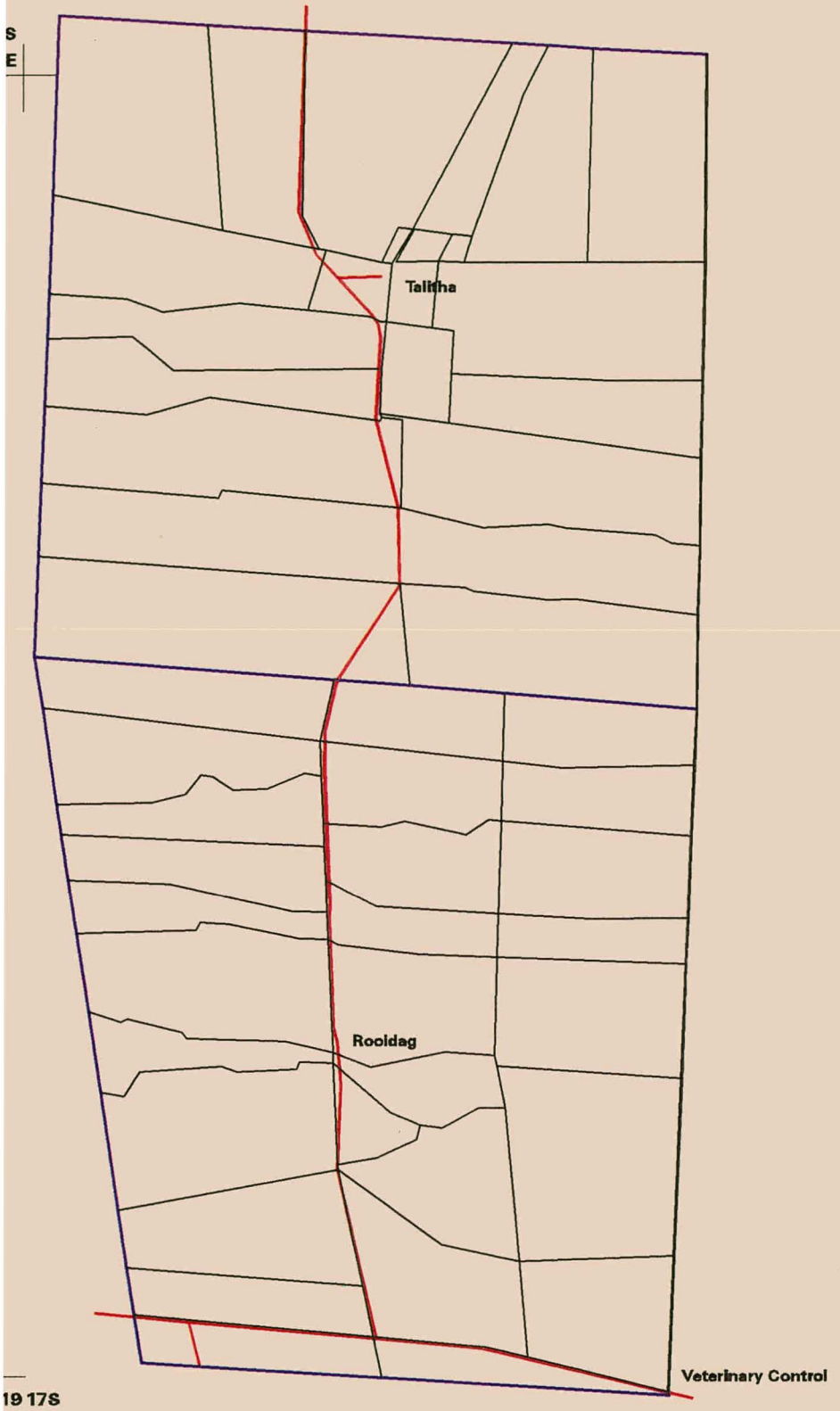
The secondary roads depicted on the topographic maps did not always match those visible on the images. It was assumed that the roads had been relocated after the maps had been compiled and the information provided by the images was considered to be the most accurate representation available. This interpretation was verified in the field.

It was found, that the clear definition of boundary fence lines on the SPOT image was caused by fire-breaks or maintenance tracks adjoining the fences, and which had been almost entirely cleared of vegetation.

The results of the interpretation are provided in Map 4: "*Infrastructure*"

18.2 Land Use

In view of the importance of land use, in particular grazing, in the context of this study, it was considered necessary to delineate land use units within the study area, both within the



19 07S
19 15E

19 17S
19 08E

19 17S
19 15E

0km 5km

Map 4. Infrastructure

Farm Boundary

Camp fences

Veterinary Cordon Fence

Secondary Roads

Projection: UTM 33

Source: SPOT XS

farming zone and in the communal area east of the veterinary cordon fence.

Previous experience showed that the predominant form of land use west of the veterinary cordon fence was pastoral farming, with a small amount of cultivation in the streets. Little agricultural land use, if any, could be found in the eastern part of the study area, although a visit a year after the field assessment showed that pastoral farming had started.

The location of the veterinary cordon fence was determined on topographic maps and compared to SPOT images. The clarity of the cordon fence on the images facilitated distinction between the commercial farming zone and the communal lands.

Cultivated areas were easily detected on the SPOT image as almost white areas with straight borders. Initially, confusion arose between cultivated lands and areas cleared of bush to improve grazing. During the initial field assessment it was determined, however, that areas cleared for improved grazing were marginally darker in colour on the image than cultivated lands.

A number of gravel pits also showed up as white areas, but their borders were irregular, unlike those of cultivated lands. Although gravel pits and cultivated lands could be identified on the SPOT image the features are not indicated on the map.

Discussions with farmers and observations in the field showed that *P. angolensis* had been exploited in the western parts of the area during the 1960's. Unfortunately no records of the harvesting practices or extracted timber volumes were available.

18.3 Topographical Features

The streets were visible as red bands on the SIM's, frequently with a coarser texture than the dune ridges. In addition, a number of coarse patches were visible in the street areas. These were later identified as pans, which support a different vegetation on heavier soils than the surrounding areas.

Dune ridges showed as light beige areas with a central band darker than the sides.

Differences in colour and texture were evident between areas to the west and east of the veterinary fence. Areas on the western side showed up lighter in colour than those on the eastern side, and were of a much coarser texture. Similar trends could be seen on the aerial photos.

Dune ridges and streets were clearly defined in the farming area, while the transition between them in the area east of the cordon fence was more gradual. The clear definition on the western side was assumed to arise from veld management

practices on the farms. Dune and street vegetation are managed in separate camps, since the species composition of the two vegetation types require different management regimes (Vermaak *pers. com.* 1994, Harmse *pers. com.* 1994).

The delineation of topographical features was evaluated during ground truthing in the study area, and necessary corrections were made.

Since the delineation of the vegetation in the study area was based on the same principles, the topographical features closely match the vegetation types shown on Map 5.

18.4 Vegetation Types

The delineation of vegetation on the SIM's in combination with the initial ground truthing resulted in the vegetation types depicted on Map 5 "*Preliminary Vegetation Map of the Study Area*", and with the following descriptions:

Dune Vegetation

This vegetation type is found on the slopes and ridges of dunes and consists mostly of *Burkea africana, Terminalia sericea, Combretum apiculatum, Combretum zeyherri, Ochna pulchra* and *Pterocarpus angolensis. Baphia massaiensis* (subsp. *obovata*) was often seen in the road reserves or adjacent to fire-breaks along fence lines, but is well represented within the vegetation as a whole. During the field survey in 1994 the

genus *Commiphora* was frequently encountered, although no leaves fruit or flowers were present to permit species identification. Occasionally, members of the genus *Grewia* were also encountered.

Photo 7. Dune vegetation on Farm Rooidag (F.P. Graz, October 1994)

Street Vegetation

Vegetation classified as street vegetation occurs at the foot of the dune ridges and spreads through the areas between them. The most important species in these areas are *Acacia mellifera, Acacia fleckii, Acacia erioloba, Bauhinia petersiana, Dichrostachys cinerea* and a few *Acacia ataxacantha.* As stated

earlier, a number of pans have also been identified in the streets, but their species composition was not recorded.

Photo 8. Street vegetation on Farm Rooidag (F.P. Graz, October 1994)

'Broken Dunes' and Transitional Vegetation

Areas in which species from both dune and street vegetation are represented were classified as transition zones . The species composition of the vegetation associated with this zone changes gradually from one vegetation type to the next. The closer a dune ridge is approached the more dominant the species associated with dune vegetation becomes. This gradual change is less evident in the farm zone due to the vegetation specific management practices.

Map 5. Preliminary Vegetation Map of the Study Area

- Dune Vegetation
- Street Vegetation
- Transitional Vegetation Type
- Broken Dune
- Farm Boundary
- Camp fences
- Veterinary Cordon Fence
- Secondary Roads

N

Projection: UTM 33

Source: SPOT XS

The broken dune vegetation also shows a mixture of species from the dune ridges and streets, and thus corresponds to the transition vegetation in composition. However, the position of this vegetation type was more associated with streets. The vegetation was therefore indicated separately. The name 'broken dune' is a direct translation of the name "gebroke duin" given by the local farmers to describe very low dune ridges with the characteristic species mix.

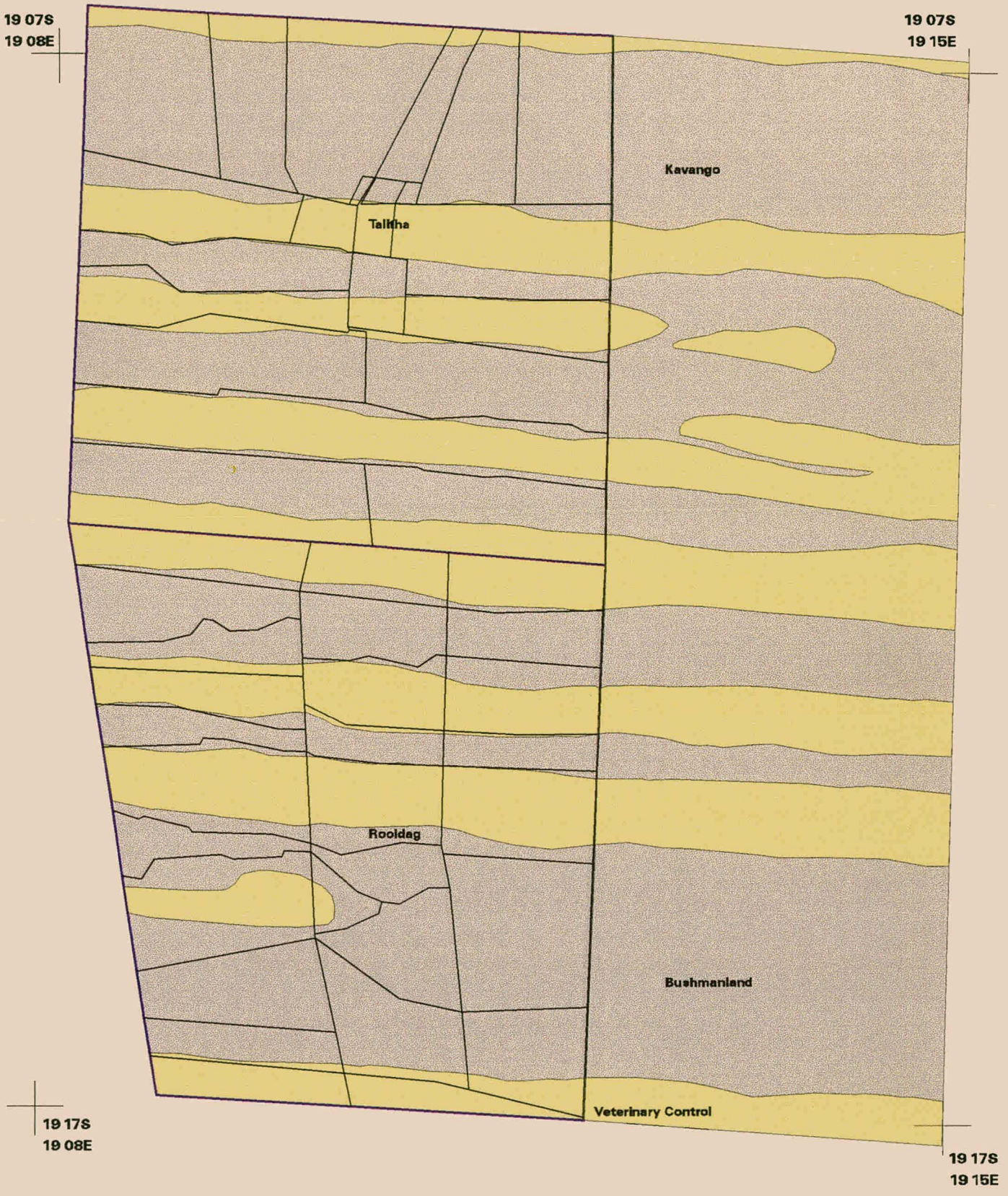
19. FINAL STRATIFICATION OF THE STUDY AREA

In line with the objectives of the study, and within budgetary constraints, measurements were limited to the dune vegetation in which the species *P. angolensis* occurs.

To reduce the total variation of the variables that were assessed in the study area (Mueller-Dombois and Ellenberg 1974), the area was stratified into a number of enumeration areas on the basis of the factors delineated as above.

The enumeration areas were sub-divided on the basis of land use and the vegetation classes identified above. In practice the developed infrastructure, particularly the fences and roads, were used to delineate the enumeration areas within the farming zone. On the eastern side of the cordon fence only dune, broken dune and street vegetation were identified, and only the dune vegetation was sampled.

The following map, map 6 "*Stratification of Enumeration Areas*" depicts the enumeration areas identified.



Map 6. Stratification of Enumeration Areas

Sample Areas

Farm Boundary

Camp fences

Veterinary Cordon Fence

N

Projection: UTM 33

Source: SPOT XS

PART 5. FIELD SURVEY

20. MATERIALS AND METHODS

Mueller-Dombois and Ellenberg (1974) recommend that clear definitions are established prior to an enumeration, to reduce bias at a later stage. The variables listed in Table 3 were therefore identified.

Table 3. The definition of variables used in the enumeration of the dune vegetation.

Variable	Description
Growth Forms:	
Tree:	A tree with a single stem, and with no regeneration from the base.
Regenerative tree:	A tree with a single stem, as well as regeneration from the base.
Light shrub	Woody plant with 2 - 4 stems at the base.
Bushy shrub	Woody plant with 5 or more stems at the base.
Tussock / Seedling:	Seedling or suffruticose tree form regenerating from ground level. Includes coppice of felled trees.
Grass:	Single "stemmed" or tussock grass.
Other herbaceous forms:	Any other growth form of herbaceous plants including forbs, creepers etc.
Plant height	Height of the tallest stem of a plant, in centimetres.

Land Use:	
Pastoral Farming:	Use of land for grazing of domestic stock.
Other Land Use:	Any other form of land use.
None:	No apparent land use.
Soil:	
Soil texture	Percentages of each particle size class present.
Soil chemistry:	Concentration of nutrients.
Distance to nearest plant:	Shortest distances in centimetres.
Position of Water points:	Geographic location of drinking places for domestic stock.
Start and End of Transects	Geographic location.

For the assessment of *P. angolensis* the following definitions are given:

Table 4. The definition of variables used in the enumeration of *P. angolensis*.

P. angolensis	
Growth Form:	Tree, regenerative tree or seedling/suffrutex (see table 3).
Height:	Height of the tallest stem, in meters.
Diameter:	Diameter (in centimetres) at breast height (1.3m above ground) of the tallest stem.

To determine the most suitable sampling strategy a number of factors were considered.

Mueller-Dombois and Ellenberg (1974) consider that plants are generally distributed non-randomly. This causes difficulties in applying a statistical error term and in determining a suitable sampling size and sample plot size (Mueller-Dombois and Ellenberg 1974, Hutchings 1986); although Coetzee and Gertenbach (1977) provide a system which may permit an appropriate plot size at each individual sampling location.

As an alternative Mueller-Dombois and Ellenberg (1974) have suggested that a 'running' mean should be plotted during the assessment. However, if a variable is expected to change systematically, such as soil factors in relation to distance from watering points, this technique is not appropriate.

Sampling by belt transect such as described by Kent and Coker (1995) does not detect systematic changes since positional information is not recorded.

Due to limited visibility in parts of the study area it is difficult to identify boundaries of sample plots unless they are physically delimited. The time required to lay out plots in this manner was beyond the means of the project.

In view of these considerations sampling was plotless and the Point-Centred Quarter (PCQ) method discussed by Heyting (1968) and Mueller-Dombois and Ellenberg (1974) was applied.

This method makes allowance for the difficult access and visibility which are experienced in parts of the study area, and does not require decisions of whether borderline cases fall within a plot or not.

Transects were therefore run along the crests of each dune with sampling points at intervals of 50m. At each point the distance to the nearest plant was measured in each quadrant of a cross projected on the sample point. Keeping in mind the relationship between the herbaceous and woody vegetation discussed previously the two components were measured separately at each sample point.

The woody plants were identified where possible. Difficulties arose, where plants had been severely damaged by fire, or where plant material was insufficient for a positive identification. Also, a number of plants could only be identified to genus.

P. angolensis was sampled separately from the general vegetation in a 20m wide belt transect. The centre line of the belt transect and the line for the PCQ transect ran concurrently.

In order to permit comparisons between the general vegetation and parameters measured for *P. angolensis* the belt transect was divided into 50m long sections, the end points of which coincided with the PCQ points.

P. *angolensis* density was related to a point by the average density of trees over 50m of the belt transect on either side of that point.

In view of the importance of soil in the woodland ecosystem, soil samples were taken in conjunction with samples of the vegetation at 500m intervals along the transect. Due to the loose texture of the soil, samples were taken with a spade rather than with a soil auger.

Soil samples were taken at every tenth vegetation sample point, at depths of 0cm-5cm and app. 70cm. The two depths were chosen since the top soil is the layer most affected by fire and herbivore impact.

The deeper sample was used to sample the root zone. Literature on the root systems of some species which occur in the study area provide the following measurements on root penetration: the roots of *Burkea africana* extend 50-60cm into the soil (Yeaton 1988), those of *Terminalia sericea* 12-23cm (Smith and Grant 1986, Yeaton 1988) and the lateral roots of *P. angolensis* occur mostly at 30-60cm although numerous sinkers are sent down

to a depth of 2m (Vermeulen 1990). In addition, the upper 45-90cm are colonised during the first year of development of a *P. angolensis* seedling (Vermeulen 1990). The sampling depths effectively cover the rooting zones.

The soil samples were analysed by the Soil laboratory of the Ministry of Agriculture. The procedures used to determine of the concentration of elements are provided in Appendix 3.4

The field enumeration was carried out in the first three weeks of October 1994 prior to the first rains in the study area. The synchronised flowering of *P. angolensis* described by Childes (1989) was observed during the first week. Leaves sprouted only after most trees had lost their flowers. The maximum daily temperature during the field work ranged between 37°C and 42°C.

Fourteen transects were measured, four of which were laid out in the communal area. One transect in the farming area was not completed when it was found that it extended through a maintained quarantine camp next to the farmstead; all undergrowth and scrub had been removed. The results of this transect were therefore discarded during data analysis.

The first transect was used as a trial for the implementation of the enumeration strategy and no soil samples were taken. Four transects were measured on the farm Rooidag and a further

five on farm Talitha. The remaining transects were laid out on the first four dune ridges north of the road to Tsumkwe, starting at the veterinary cordon fence. The vegetation on three of these dune ridges had burnt that season.

Statistics were calculated using the package Statistica 4.5.

21. RESULTS

21.1 Analysis of Vegetation Data

21.1.1 Vegetation Density

The data was examined by calculating the mean distance to the nearest plant for individual transects and for the communal area and the farms as a whole. These statistics are provided in Table 5 below.

Table 5 shows that the mean distance from a sample point to the nearest herbaceous plant is markedly lower than to the nearest woody plant.

The statistics in Table 5 suggested the possibility of a relationship between land use and vegetation density. To determine such a relationship, an Analysis of Variance was carried out for both, woody and herbaceous vegetation densities. The results - provided in Table 6 - show that there are significant differences in the distance to the nearest plant on the two farms and in the communal area, with vegetation more dense on Talitha. The mean distance to the

nearest herbaceous plant is less in the communal area than on the farms.

Table 5. Mean of the distances (in centimetres) to the nearest woody or herbaceous plants and mean plant height, for each transect measured, and as a total for the farms and communal area. The overall variance is provided in brackets.

		Woody Vegetation		Herbaceous Vegetation	
Location	N	Mean Distance	Mean Height	Mean Distance	Mean Height
Communal Area	200	192.2	150.9	37.8	38.0
	180	198.8	145.1	28.6	27.3
	160	157.6	127.8	26.1	39.7
	160	198.5	143.8	38.1	35.6
Mean	700	187.43	142.5	32.82	25.07
Variance		(10138.53)	(9881.70)	(490.19)	(1357.05)
Farm Rooidag	76	207.4	164.9	62.8	62.0
	160	208.8	190.8	46.9	47.3
	160	204.8	179.0	42.6	54.4
	182	147.8	143.9	40.5	35.1
Mean	578	187.32	169.28	45.76	47.31
Variance		(11605.10)	(13170.82)	(1150.00)	(1538.39)
Farm Talitha	198	163.0	154.4	41.4	51.1
	160	170.3	111.3	39.2	46.9
	180	145.4	134.6	39.8	34.9
	160	168.0	153.3	27.5	47.8
	180	186.2	134.0	40.0	32.9
Mean	898	167.06	140.11	37.64	42.19
Variance		(7820.93)	(12024.35)	(727.95)	(1478.22)

Table 6. The results of ANOVA's to determine differences in vegetation density and the height of woody plants on the farms and in the communal area.

	Woody Vegetation		Herbaceous Vegetation
Statistic	Mean Distance	Mean Height	Mean Distance
F	11.59353	14.51044	35.83725
Farms df	2	2	2
Error df	2173	2173	2173
p	0.000010	0.000001	0.000000

21.1.2 Plant Height

To determine difference in plant height between the communal area and farms an Analysis of Variance was carried out on the height data of the woody plants. The results of the analysis showed that there is a very significant difference ($p < 0.0001$) in woody plant height between the three areas. Woody plants on the farms were generally taller than in the communal area.. Since height measurements of the herbaceous plants could not be taken at all sample points on three transects in the communal area, no ANOVA was conducted on the herbaceous plant height.

Further statistics were calculated to determine the existence of simple linear correlation between woody and herbaceous vegetation parameters and the results are provided in Table 7.

The table shows that a significant correlation between woody and herbaceous plant densities exists only on Farm Rooidag.

Significant linear correlation was also found between the distance to the nearest woody plant and woody plant height, as well as between the distance to the nearest herbaceous plant and herbaceous plant height.

Table 7. The correlation coefficients, r, and probability, *p* (bracketed), determined for simple linear relationships between vegetation density and height. Significant correlations ($p < 0.05$) are underlined.

Location	N	W-Dist vs. H-Dist	W-Dist vs. W-Hgt	H-Dist vs. W-Hgt	H-Dist vs. H-Hgt	H-Hgt vs. W-Dist
Communal Area	700	-0.0313 (0.408)	0.1302 (0.001)	-0.0504 (0.183)	0.0704 (0.063)	-0.0576 (0.128)
Farm Rooidag	578	0.1220 (0.003)	0.2494 (0.000)	0.0223 (0.593)	0.2984 (0.000)	0.0325 (0.436)
Farm Talitha	898	-0.0508 (0.128)	0.2527 (0.000)	-0.0317 (0.342)	0.2307 (0.000)	0.0303 (0.364)

The relationship between the herbaceous plant density and height was restricted to the farms and the unburnt area in the communal lands.

21.1.3 Growth Forms

The occurrence of growth forms of woody plants in the different areas is shown in Table 8. It is evident that the greatest portion of the woody plants were represented by shrubs. Most of these were classed as bushy, i.e. shrubs with five shoots or

more. Regenerative forms - seedlings or suffrutex "tufts" and regenerative trees, were poorly represented.

The results of a Chi-square analysis showed very significant differences in growth form distribution between the farms and between the farming and communal areas. Woody plants in the communal area were primarily represented by bushy shrubs, while fewer trees and regenerative forms occurred there.

The proportion of shrubs in the farming area was generally lower than in the communal area, although proportionally more bushy shrubs occurred on farm Talitha than on Rooidag.

A larger proportion of trees and light shrubs was found on Rooidag than on Talitha, while there were more regenerative plants found on Talitha.

A correspondence analysis such as described by Jongman *et al.* (1987) indicated that the growth forms on farm Talitha followed an intermediate distribution between farm Rooidag and the communal area. The scatter plot in figure 7 also shows a clear distinction between the transects that had been burnt that season and the unburnt transect in the communal area.

Table 8: The actual and expected (bracketed) frequencies of woody plant growth forms. The Chi-square analysis showed that there is a significant difference in the occurrence of plant growth forms between the three identified areas.

	Growth Forms of Woody Plants					Row Totals
Location	tr	rt	ls	bs	s	
Communal Area	20 (42.78)	20 (38.28)	109 (145.40)	515 (403.40)	36 (70.13)	700
Farm Rooidag	63 (35.33)	37 (31.61)	179 (120.06)	223 (333.09)	76 (57.91)	578
Farm Talitha	50 (54.89)	62 (49.11)	164 (186.53)	516 (517.51)	106 (89.97)	898
Column Totals	133	119	452	1254	218	2176

Pearson Chi-square = 180.432; df = 8; p = 0.0000

Where:

tr = tree, rt = regenerative tree,

ls = light shrub, bs = bushy shrub,

s = seedling.

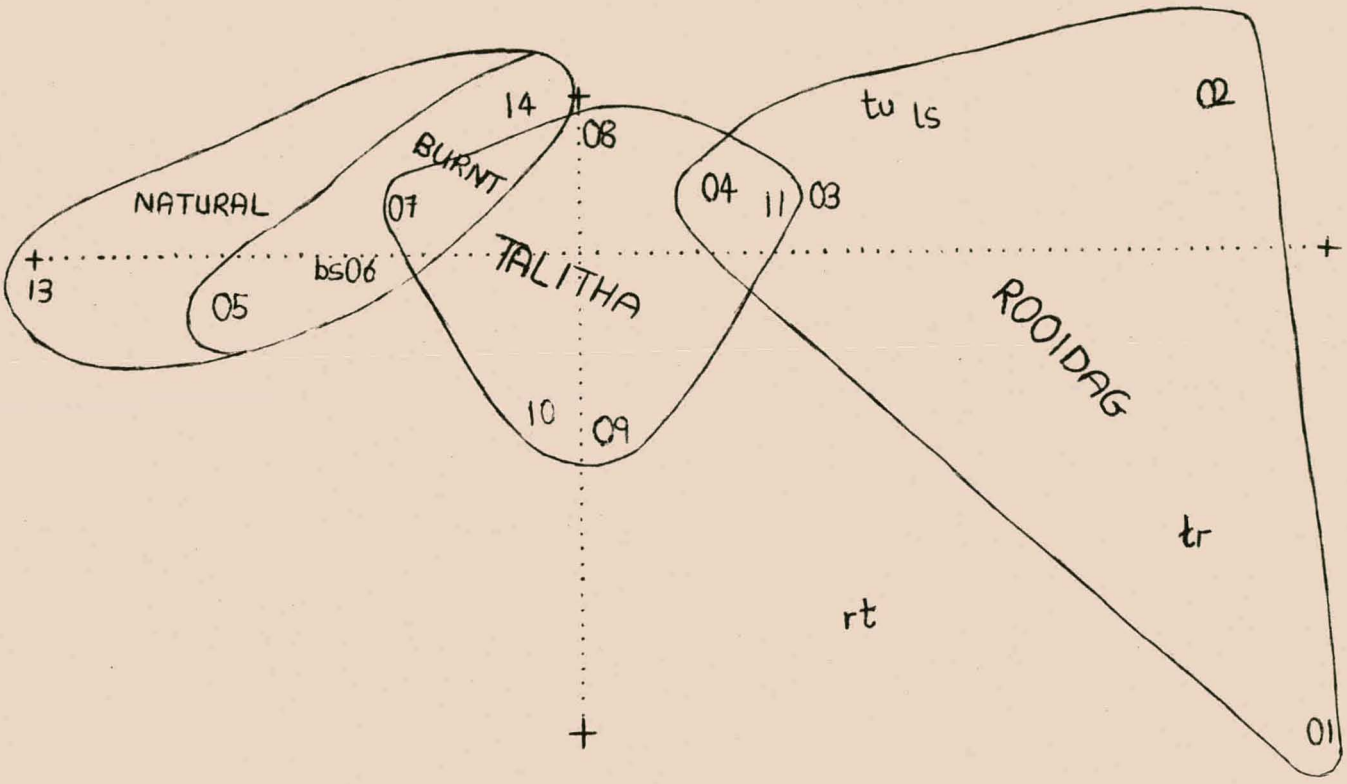


Figure 7. The scatter diagram obtained from a correspondence analysis carried out on the plant growth forms identified during the field survey. The numbers indicate transects. There are definite groupings of growth forms based on land use.

21.1.4 Species

The species which were identified during the enumeration are provided in Table 9 below. It is evident from this table that species distribution is linked to land use and fire.

Baphia massaiensis occurred most frequently - up to 25.7% of the woody plants, and provided the largest proportion of plants in the communal area and on Talitha. Second most frequent *was Terminalia sericea*, with a distribution between the farms similar to that of *Baphia massaiensis*. Members of the genera *Combretum* and *Commiphora* were found more frequently on the farms, with *Commiphora* represented most frequently on Talitha.

Table 9. The species identified in the study area, as well as their occurrence as percentage of the number of observations in each area.

Species	Communal Area	Farm Rooidag	Farm Talitha
Acacia spp	1 (0.1%)	0 (0.0%)	8 (0.9%)
Baphia massaiensis	229 (32.7%)	57 (9.8%)	275 (30.6%)
Bauhinia petersiana	18 (2.6%)	14 (2.4%)	45 (5.0%)
Burkea africana	18 (2.6%)	5 (0.9%)	3 (0.3%)
Combretum spp	15 (2.1%)	98 (16.9%)	94 (10.4%)
Commiphora spp	19 (2.7%)	22 (3.8%)	142 (15.8%)
Dichapetalum cymosum	0 (0.0%)	2 (0.3%)	0 (0.0%)
Baikiaea plurijuga	0 (0.0%)	0 (0.0%)	6 (0.7%)
Grewia flava	5 (0.7%)	15 (2.6%)	45 (5.0%)
Lonchocarpus nelsii	4 (0.6%)	16 (2.8%)	18 (2.0%)
Ochna pulchra	23 (3.3%)	14 (2.4%)	21 (2.3%)
Pterocarpus angolensis	11 (1.6%)	2 (0.3%)	5 (0.6%)
Strychnos sp.	1 (0.1%)	0 (0.0%)	0 (0.0%)
Terminalia sericea	107 (15.3%)	38 (6.6%)	103 (11.4%)
Ricinodendron rautanenii	0 (0.0%)	0 (0.0%)	1 (0.1%)
Unidentified species	249 (35.6%)	297 (51.2%)	134 (14.9%)

Other species, which did not appear in the enumeration but could be positively identified included *Grewia flavescense* and *Securidaca longipedunculata*.

21.2 P. angolensis in the study area

21.2.1 P. angolensis density

To investigate the relationship between *P. angolensis* and the remaining vegetation, the correlation between the density of *P. angolensis* and the distance to the nearest woody and herbaceous plants was calculated for each transect. The correlation was very low, and statistically insignificant.

The same relationship was investigated for the pooled data. The results of this calculation are provided in Table 10. From the table it is evident that no significant correlation exists between the occurrence of *P. angolensis* and other woody plants, or the herbaceous vegetation components.

Table 10. Correlation between the density of *P. angolensis* and the surrounding vegetation. No significant correlation exists at p = 0.050.

Item	Value
Sample size	545
Correlation Coefficient (r)	0.0393
p	0.360

21.2.2 Height and Diameter Relationships

A very significant simple linear correlation was found to exist between the height and diameter of *P. angolensis* when all measurements were pooled. Table 11 provides a summary of the relevant statistics.

Table 11. Correlation between *P. angolensis* diameter and height, and the correlation between vegetation density and *P. angolensis* height. The H_0: r = 0 (there is no correlation) is rejected with p << 0.05.

Relationship	Sample Size	Correlation Coefficient	p
P. angolensis diameter vs. height	531	0.852	0.000
Vegetation density vs. *P. angolensis* height	521	-0.147	0.001

A further significant correlation was found between the height of *P. angolensis* and the density of the surrounding vegetation. Lower tree height for *P. angolensis* is associated with dense woody vegetation, while taller *P. angolensis* were found in areas with less dense vegetation. A summary of the statistics is also provided in Table 11.

Despite the diameter-height relationship for *P. angolensis* trees, no significant correlation (r = 0.36, *p* = 0.0393) was

found between the density of the general woody vegetation and tree diameter.

There are differences in the distribution of the height of *P. angolensis* plants between the farms and communal areas. On the farms 12% of the plants are five meters or less in height, while in the communal area this height class makes up over 40%. Plants between five and ten meters make up 80% in the farming area and 53% in the communal area. The remaining 8% and 7% are plants taller than 10m in the respective areas.

21.2.3 Growth Forms

A summary of the distribution of growth forms of *P. angolensis* found in the study area is provided in Table 12. The table shows that the greatest proportion of plants counted were non-regenerative trees, particularly in the farming area. The regenerative tree form was more common in the communal area.

Table 12 also provides the results of a Chi-square analysis which shows very significant differences in the occurrence of the different growth forms on the farms and in communal area.

Few trees, i.e. 12% of those measured in the farming area, and 23% in the communal area were regenerative In the communal area 19% of plants were seedlings or suffrutexes while regeneration in the farming area was found only on Talitha. In all, 42% of *P. angolensis* plants in the communal area were

regenerative, while the equivalent figure for the farming area is only 12%.

Table 12. The actual and expected (bracketed) frequencies of growth forms of *P. angolensis*. There is a significant difference in plant growth forms between the three identified areas.

Location	***P. angolensis* Growth Forms**			**Row Totals**
	tr	rt	tu	
Communal Area	169 (208.79)	66 (42.74)	56 (39.46)	291
Farm Rooidag	142 (108.34)	9 (22.04)	0 (20.47)	151
Farm Talitha	70 (63.86)	3 (13.07)	16 (12.07)	89
Totals	381	78	72	531

Pearson Chi-square = 75.98; df = 6; p = 0.00000

tr = Tree form;

rt = regenerative tree;

tu = suffrutex.

21.3 Analysis of Soil Data

21.3.1 Concentration of Elements in the Top-Soil and Sub-Soil

A paired-sample t_test was carried out to test for a difference in the concentration of elements between the top-soil and sub-soil. The results are provided in Table 13. Underlined values

indicate where differences were found to be statistically significant ($p < 0.05$).

The table shows that consistent differences in the exchange capacity, the pH and in the concentration of P exist between top-soil and sub-soil. Further differences were found to exist for Mg, Ca and on farm Rooidag, but not on Talitha.

Table 13. The mean concentration (ppm) of elements in the top soil (0cm) and sub-soil (70cm), as well as the results of a paired sample *t*-test to determine differences between top-soil and sub-soil concentrations. Significant differences at $p = 0.05$ are underlined.

Location	Soil Depth	*df*	K	Mg	P	Ca	Na	pH	EC
Communal Area	0 cm	21	43.36	17.62	3.19	70.67	15.32	4.73	74.86
	70 cm	21	16.82	5.71	1.91	20.09	14.36	4.08	26.55
	p		0.034	0.248	0.005	0.116	0.465	0.000	0.000
Farm Rooidag	0 cm	15	27.63	12.25	3.50	40.25	14.25	4.21	55.81
	70 cm	15	32.81	4.56	2.03	24.50	14.06	3.99	18.25
	p		0.568	0.000	0.002	0.000	0.851	0.000	0.000
Farm Talitha	0 cm	29	36.63	21.07	3.07	48.13	15.37	4.47	64.50
	70 cm	29	30.73	14.47	1.83	36.43	14.87	4.25	30.37
	p		0.093	0.071	0.011	0.132	0.536	0.014	0.000

21.3.2 Concentration of Elements vs. Distance to the Nearest Plant

No significant correlation was found to exists on a consistent basis between the distance to the nearest herbaceous plant and the quantity of any of the elements examined in the top-soil.

Similarly, no consistent correlation could be found between elements in the sub-soil and distance to the nearest woody plant.

22. DISCUSSION

22.1 Plant Density

No evidence was found to support the relationship between the density of woody and herbaceous vegetation as initially postulated. Rather, the two components seem to vary independently.

Further consideration of these results indicates that the lack of a relationship is brought about by the rate at which the herbaceous vegetation may respond to outside influences. For instance, woody plants can only respond to rainfall once water has percolated to the lower soil layers (Walker and Noy-Meier 1982). Herbaceous plants, on the other hand, are able to respond much faster, especially if rainfall is low.

Conclusions based on one set of measurements are therefore inadequate. Repeated enumerations need to be made to account for the slower development of the woody vegetation.

The inverse relationship between height and density found within both the woody and herbaceous vegetation components indicates that there is competition within each component.

The mean distance to the nearest woody plant in the communal area is generally higher than the corresponding figure on Talitha, but almost equal to that on Rooidag. This suggests that the prolonged low grazing intensity experienced on Talitha permits an increase in the density of the woody vegetation. (Prolonged heavy grazing causes the development of a lower woody plant density, since animals will browse young seedlings when the herbaceous cover is low.)

The fires which occur in the communal area would promote a less dense woody vegetation by killing seedlings. This enhances the structural differentiation between the communal and farming areas.

Additional support for differences in the vegetation is provided by the SPOT image used in the mapping of the study area. The image shows clear differences in colour between the farms, making it possible to distinguish farm and camp boundaries.

The postulated increase in plant density with increasing distance from a water hole was not evident in the data. Some relationship must exist, however, since there were often clear signs of heavy grazing and browsing at focal points such as road sides, gates, or water holes. At 100m into the transects, however, these signs had almost disappeared.

The absence of a relationship between the density of woody plants in general and *P. angolensis* is linked to the establishment and growth requirements of the species. According to Vermeulen (1990) *P. angolensis* colonises open areas, where there is little competition. Other woody plants which are more tolerant of competition may establish themselves later.

If a relationship exists between *P. angolensis* and the remaining woody plants, it has been obscured by the removal of trees. Tree densities in the communal area may have been higher in the past, but harvesting in the area during the 1960's has reduced the tree population.

22.2 Plant Height

A comparison of the data summarised in Tables 5 and 8 showed that mean plant height is greatly influenced by the number of shrubs - light or bushy - found in an area.

Also, since the herbaceous plants of three transects in the communal area had in some cases been reduced almost entirely to ground level by fire, the lack of correlation between herbaceous plant density and height in the communal area should not be considered conclusive.

Considering that *P. angolensis* usually occurs in even aged stands (Groome *et al.* 1957b), and that trees which grow up together are generally of equal height (von Breitenbach 1973) it is evident that the sub-population of the communal area has a healthier structure than that of the farming area, that is, the size classes are more evenly distributed, with a strong component of young plants. On the other hand, further investigation of the regeneration closer to the veterinary fence showed that a large portion of the plants were coppice material.

These observations are similar to those of Geldenhuys (1992) who found that the smaller size classes of *P. angolensis* had a higher stem density in Kavango. This he attributed to the higher fire tolerance of the species.

22.3 Growth Forms

Bushy shrubs were particularly dominant in the communal area, making up 74% of all woody plants observed. During the field count many of the multi-stemmed shrubs seemed to have been killed by fire. Closer examination of the individual plants

showed, however, that almost all were forming new shoots at the base, leading to the development of dense bushes/shrubs. This was especially noted for *Baphia massaiensis*, which was also the most commonly observed woody species.

Regenerative forms, such as regenerative trees, seedlings or tussocks of woody vegetation were found to be less frequent in the communal area. It is likely that fire killed most seedlings in the area and caused damage to coppice material. Also, the higher density of herbaceous vegetation in the communal area has probably suppressed seedling development.

The differences in the proportion of growth forms between the farms is brought about by differences in range management, and is also reflected in the species composition. As indicated previously, *Baphia massaiensis* occurred most frequently in the communal area and on farm Talitha. This species was found only as light or bushy shrub, although it may form a small tree (Coates Palgrave 1983). Similarly, *Commiphora* spp. also mainly occurred in shrub form.

No differentiation was made between coppice regeneration and suffrutexes of *P. angolensis*. The low number of trees on farm Talitha as well as the presence of dead stumps indicate that some exploitation of the species had occurred in the past. The high occurrence of suffrutex / coppice regeneration on this farm - as compared to Rooidag - would suggest that most of the

regeneration is coppice. It must be considered that seed of the species does not germinate well in shade conditions (Groome *et al.* 1975b) such as found on the farms. This provides further support for the assumption that regeneration on Talitha is primarily coppice material.

22.4 Soils

Although soil moisture was not measured it was observed that water would condense on the inside of sampling bags containing soil from 70cm depth. No condensation could be seen in the sample bags containing top soil. Soil moisture is therefore considered to be higher in the sub-soil. Further discussions with the farmers indicated that moisture could be found in lower soil layers even at the end of the dry season in very dry years.

22.5 General

The field survey was intended to confirm the applicability of the previous knowledge to Namibian conditions.

The clearest relationships between land use and vegetation are evident in growth forms and species. Both factors cause differences in the vertical structure of the vegetation.

Although correlation between woody and herbaceous plant densities and their height exists, it indicates the importance of competition within each of the two components rather than

between them. The correlation between the woody and herbaceous vegetation density was not conclusive. This lack of decisive evidence must be seen in terms of the lack of temporal replication of measurements to make allowance for the effects of short term variations in the vegetation composition.

Further research in vegetation development must take both the spatial and temporal scale of the savanna woodlands into account. The study shows, that there are strong variations in species composition and other vegetation parameters, which need to be considered. Vegetation density, on the other hand, must be considered in terms of the time it requires to respond to rainfall and the effects of fire.

PART 6. MODELING

23. SELECTION OF THE MODELLING APPROACH

23.1 Criteria for Model Selection

As outlined in the introduction, a model may be used to facilitate further understanding of the development of *P. angolensis* populations. In order to select the model which will serve the purposes of this study most effectively the following criteria must adhered to.

Generally, the model must cope with a severe lack of statistical data, but must nevertheless provide information pertaining to the development of *P. angolensis* under the influence of the key factors that have been identified, i.e. rainfall, competition and fire.

In view of the uncertainty regarding the full impact of fire on the development of a *P. angolensis* population the model must provide the opportunity to investigate the influence of this factor in particular.

The model must furthermore, provide an opportunity to investigate the effects of exploitation and grazing on the development of the *P. angolensis* population as a whole.

The scope of potential models is restricted by the limited information. Considering the lack of empirical data regression

models as described by von Gadow and van Hensbergen (1987) or matrix models such as discussed by Leslie (1945) or Suzuki (1984) cannot be compiled at this stage.

An illustration systems-model may be developed, however, in which the actual processes are of primary importance. This type of model emphasizes the linkage between the components rather than their status (Pellew 1983).

23.2 Choice of a Model

23.2.1 Stage Structured Models

Stage structured models divide a problem into a logical number of stages. Each of these may then be tested, tuned and/or evaluated separately to provide information on parts of the whole.

For instance, the model used by Pellew (1983) in his investigation of the *Acacia*/Elephant problem in the Serengeti divided the *Acacia* population into a number of size classes in response to size related mortality rates. The effects of elephant feeding and fire were then simulated.

Wood (1994) on the other hand, describes organisms, such as insects, which develop through a series of identifiable morphological stages. The analogy of the insect population may prove useful in the study of *P. angolensis*, since the individual plants develop through distinct stages, i.e. seed,

seedling/suffrutex and adult (See section 7.). The approach considered here provides the possibility of handling each developmental stage separately.

23.2.2 Qualitative Rule Based Models

Rule-based models such as described by Starfield *et al.* (1989), Starfield (1990) and Starfield *et al.* (1993) provide a qualitative rather than quantitative output. This family of models presents a means to build on existing conceptual knowledge despite a lack of empirical data, making it very attractive for this study.

Rule based models are comprised of a set of IF-THEN rules which can be formulated in plain language before they are translated to a computer language. For instance, Starfield *et al.* (1989) formulated the following rule in their management model for an estuarine lake:

> "IF the salinity level is high, AND lake level is low OR moderate THEN reeds die back within three months"

Due to the simplicity this type of model must be seen as a step towards further understanding of the system. It may provide indications where further research is required or what aspects the development of management strategies need to cater for.

24. DESCRIPTION OF THE BASIC MODEL

24.1 General Overview

24.2 The Savanna Component

The information contained in the review of savanna ecology as well as the results of the field work provide a detailed description of the problems that the model must address, and the factors it needs to take into account.

The model used here is a combination of the stage structured and rule-based approaches discussed above. It is adapted from the frame based *Brachystegia bohemii* woodland model of Starfield *et al.* (1993).

The model devised by Starfield *et al.* (1993) divides the *Brachystegia* woodlands of Zimbabwe into three stages (frames), i.e. grassland, woodland and bushland. The model is driven by rainfall which governs plant growth and fuel load development. Once plants have reached a certain stage in development, the vegetation enters the next frame.

The grassland and woodland frames used here are similar to the ones described by Starfield *et al.* (1993), while the bushland frame is omitted due to a lack of evidence and general information concerning a Bushland vegetation type in the savanna woodlands of Namibia.

The savanna system is therefore divided into two distinct frames according to the dominant forms of competition which occur. It is assumed that while competition for water dominates, the model will remain in a grassland state (grass cover regulated state). Once light becomes the limiting factor the system will switch over to a woodland state (canopy closure regulated state).

The grassland frame considers a dominant herbaceous cover while woodland is dominated by the woody vegetation component. The two frames are run independently, each governed by its own set of rules and parameters.

A transition between frames occurs when certain conditions are met. These transition rules are described in more detail later in the text, but generally represent the change between the two dominant forms of competition (for water and light).

The rules which govern the development of each frame interpret the effects of rainfall, fire and competition on the dominant vegetation component.

Figure 8, provides a schematic representation of the flow of the basic model, and shows the relationship between the individual model components.

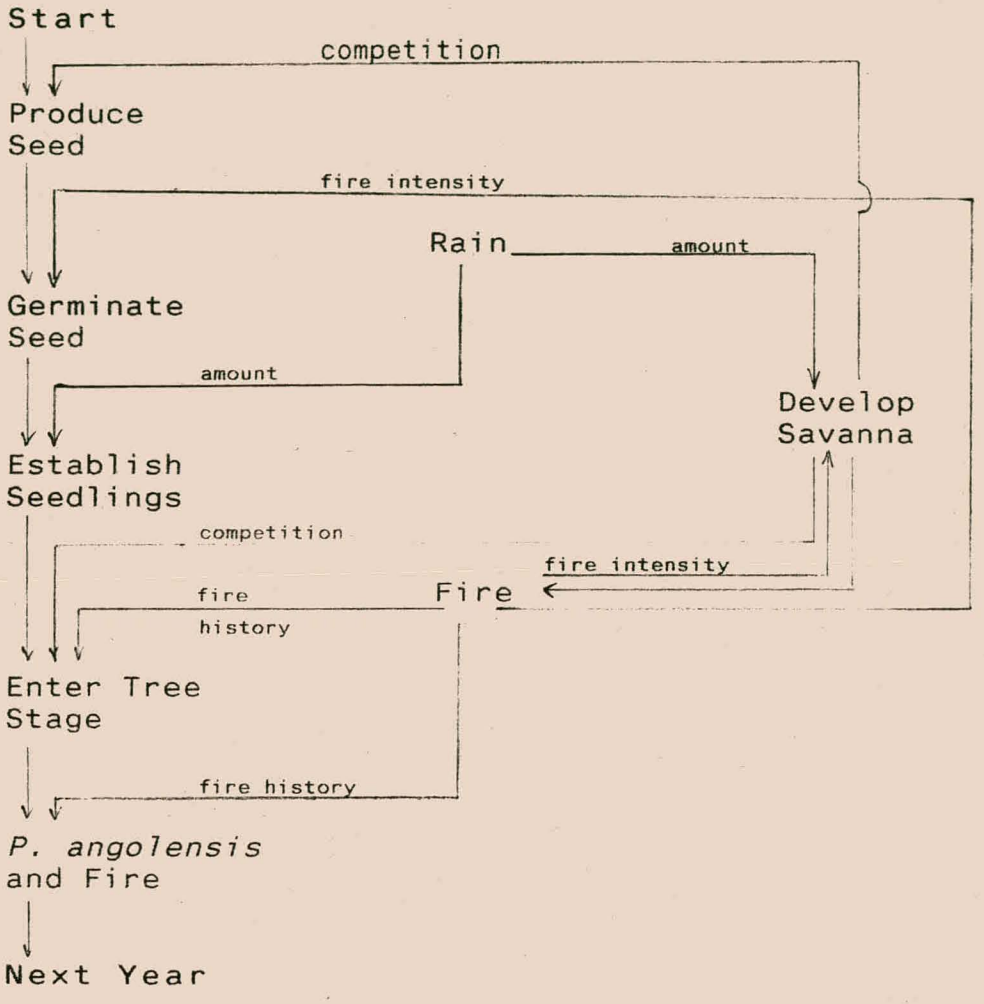


Figure 8. Schematic representation of the savanna and *P. angolensis* models, and the relationship between them.

Since the primary objective of the model is geared towards further understanding of *P. angolensis* the two frames have been kept very simple and the incorporated rules are often similar. The processes and assumptions which are described below therefore represent only the most important ones.

The statements in the following descriptions give rise either to an assumption on which the model is based, or a rule which the model must follow. Assumptions will be preceded by an upper-case 'A' while the rules are indicated by an 'r'. Where it is necessary to carry out a sensitivity analysis, rules are marked by an '*'.

24.2.1 General Assumptions for the Savanna Component

The assumptions below refer to the model as a whole.

A The degree of competition is different in each savanna frame.

A Low and high fire intensities are different in each savanna frame.

A Productivity of the vegetation component in response to rainfall does not change over the period of the simulation.

A Grazing reduces fire frequency and intensity, and reduces competition by the grass component.

24.2.2 Description of the Grassland Frame

Grassland features a dense herbaceous layer with few shrubs and scattered trees. Competition for water in the top-soil is therefore high in comparison to the lower soil layers.

The model uses scrub height as controlling variable in the grassland frame, assuming that competition for water will inhibit height growth of the woody vegetation. Once scrub height exceeds a certain threshold competition for light becomes more important than for water, and a transition to the woodland frame takes place.

Scrub height is manipulated in a real-type variable to evaluate the effects of rainfall and fire. Scrub growth and reductions are applied to the variable through a system of look-up tables in response to rainfall events or burns.

Height is recorded as belonging to one of four classes ranging from very low to very high, i.e. from 0 to 3. The classes in turn are used as index variables for the look-up tables.

Scrub height is allocated to a class by truncating the value in the height variable. In cases where the height variable reaches or exceeds 4 the grassland remains in class 3.

Once the scrub height has reached a certain stage of development a transition to the woodland frame takes place. More specifically, a switch to the woodland frame occurs under the following circumstances:

r If the grassland has been in height class 3 for five successive years; or

r If the grassland has been in height class 3 for four successive years, there is a 75% chance that a transition will occur; or

r If the grassland has been in height class 3 for three successive years there is a fifty percent chance of a transition.

Successful recruitment of woody plants will increase if the herbaceous vegetation is decreased but will be reduced as a result of fire. The impact of fire is dependent on the season of burn and the accumulated fuel.

The response of herbaceous vegetation to rainfall is swift in the grassland frame, since little competition for light is to be expected. Fires are more frequent due to the rapid response of the herbaceous vegetation to rainfall, and the resultant build-up of small fuels. Higher fire intensities occur because of the small size of the fuels (Heikkila *et al.* 1993).

A Grassland development is linked to fire frequency and intensity.

The processes acting in the grassland frame may be summarised as indicated in the following figure, figure 9

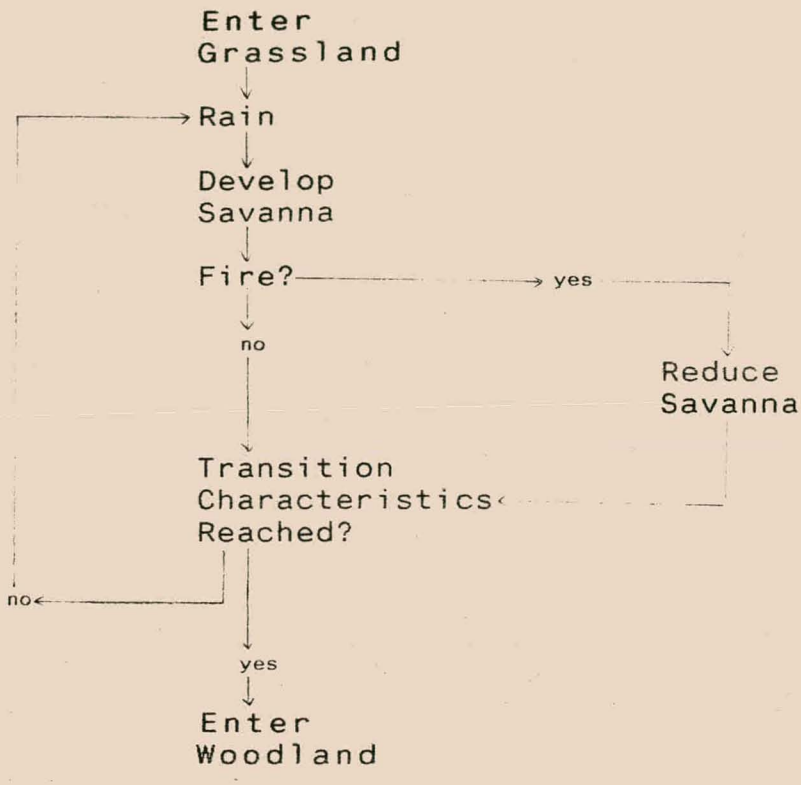


Figure 9. The structure of the grassland frame and the processes effecting it.

24.2.3 Description of the Woodland Frame

The woodland vegetation is comprised of a developed tree canopy and a shrub layer, while the herbaceous vegetation is suppressed as a result of reduced light penetration. Little of the precipitation which reaches the ground is therefore intercepted by herbaceous plants and will pass to lower-lying soil layers.

The controlling parameter in the woodland frame is the degree of canopy closure. Canopy closure is manipulated as a real-type variable which is allocated to one of four canopy classes from 2 to 5, by truncating the actual closure variable. Class 1 indicates the closure found in the grassland frame. The remaining four classes indicate closure from low (2) to very high (5). While the canopy variable itself permits more sensitive handling of canopy closure, the canopy class into which it falls facilitates easy interpretation of rules.

Canopy closure is set to 2 when the model enters the woodland frame. Subsequent development is determined by rainfall and fire, causing increases and decreases in canopy closure respectively. Should the canopy open to a certain limit, root competition again becomes the more important form of competition and the model switches back into the grassland frame.

A transition to the grassland frame occurs under the following conditions:

r If canopy closure decreases below two

r If canopy closure is in class two there is a 30% chance that a transition will occur.

Additionally,

r IF a transition to the grassland frame occurs THEN grassland height is set to 2.

Fire intensity is generally lowest in this frame. However, as the effects of successive fires accumulate, higher mortalities of trees occur and canopy closure may decline.

24.2.4 Rainfall

Rainfall is the only totally independent variable in the model, and determines the rate at which the vegetation and fuel load develop.

For the purpose of this simulation the quantity of rain is divided into two classes, high rainfall and low rainfall. Both quantities have an equal chance of occurring.

24.2.5 Fire

The occurrence and intensity of fire are dependent on the fuel that has accumulated since the previous burn, and the time of burn within the fire season.

Fuel load is recorded as a real type variable in the model, to permit a more sensitive manipulation. The effect of fuel load, is evaluated in terms of one of six fuel load classes ranging

from 'no fuel' (class 0) to 'very heavy fuel load (class 5). The classes are determined by truncating the fuel load value.

r Should the fuel load reach values exceeding 5, it will remain in class five.

Once a fire has occurred it is assumed that the entire fuel load has been consumed and the fuel load variable is reset to 0.

A All fuel is removed by a fire

The time during the fire season when a fire can occur is either early or late. Together with the accumulated fuel the timing of a fire determines the fire intensity and subsequent impact on the vegetation.

The time of the burn is then used to determine the intensity of a fire in terms of fuel load. The following rules apply:

A IF Fire burns early THEN the fire is always cool

r* IF a fire occurs THEN there is a 50% chance that early burn occurs.

r IF Fire burns late AND the fuel load is in class two THEN there is a 50% chance of a hot fire.

r IF Fire burns late AND the fuel load is in class three or higher THEN the fire is hot.

The effect of fire intensity is then evaluated together with the fuel load through a look-up table.

24.2.6 The Effect of Grazing

The response of the herbaceous layer to grazing is dependent on grazing-intensity. Light grazing is expected to stimulate tiller formation and thus increase the competitiveness of the grasses. Medium grazing intensity causes no change and high grazing intensity reduces competitiveness.

24.3 The *P. angolensis* Model

The *Pterocarpus angolensis* model which is interfaced with the savanna divides the species into three distinct developmental stages. These are the seed and seedling establishment stage, the suffrutex stage and the tree stage, each of which is treated separately in the model as described below.

24.3.1 The Seed and Seedling Stage

The seed stage extends from the time of seed production to the time when the seedlings are established.

The model uses a cohort type approach in which a constant quantity of 2000 seed is fed into the model. The controlling

rules for seed production are provided under the tree stage where 'seed production' is reduced by the degree of competition with the surrounding vegetation. The model reflects the findings of Vermeulen (1990) that:

A The size of a seed crop is related to stand openness.

This is evaluated by the following type of rule:

r* IF Canopy closure is in class 3 THEN reduce the cohort by a factor of 0.3

Further rules relate to the effect of the remaining canopy closure classes and the height classes in the grassland frame. As competition increases fewer seed enter the model.

The quantity of seed is stored in an array type variable to enable the manipulation of one seed crop for 3 years, i.e. years 0 (current) to 2.

Establishment and development of seedlings is also modified by competition with other vegetation.

A Low and high germination rates of seed are different in each savanna frame in response to the difference in competition between the frames.

In view of the effect of fire on the germination of *P. angolensis* seed (van Daalen, 1991) it must be assumed that the seed of the previous year's crop is germinated, since seed are produced in the wet season.

A The seed of the previous year or earlier is germinated in a year.

The effects of fire on germination have also been described by van Daalen (1991), and the following rules apply:

r IF fire intensity is low THEN germination rate is high

r IF fire intensity is high THEN germination rate is low

r IF No Fire occurs THEN germination rate is medium

In accordance with the descriptions of Geldenhuys (1975) the seed are only viable for one to two years.

A Seeds remain viable two years after the production of the fruit.

r IF seeds age beyond two years THEN they die.

Once the seed have been germinated the model determines how many seedlings are established in a given environment so that

they may enter the suffrutex stage. The differentiation between seed germination and seedling establishment means that even if no seedlings survive there is a reduction of the seed store.

The number of seedlings which enter the suffrutex stage is determined by the amount of rain (after Vermeulen 1990) and the competition that the plant must cope with in the suffrutex stage (after Groome *et al.* 1975b). Competition is evaluated in terms of prevalent grassland height or canopy closure, and in terms of rainfall as described below.

A Recruitment rates of *P. angolensis* seedlings will be linked to rainfall.

The following apply:

A Seedlings which are unable to establish themselves in the year in which they sprout die.

r IF rain is low THEN establishment rate of seedlings is low

r IF rain is high THEN establishment rate of seedlings is high

Additionally, competition in the grassland frame is evaluated by the following type of rule:

r* IF savanna height is in class 3 THEN a proportion of 0.6 of the seedlings may establish themselves.

Further such rules determine the effect of the remaining savanna height classes and the woodland canopy closure classes. As competition increases smaller proportions of plants enter the next stage.

24.3.2 The Suffrutex Stage

This stage extends from the time that a seedling is established to the time that it develops its first permanent shoot.

The suffrutex plants which are manipulated in the model are stored in a complex variable. This complex variable monitors the quantity of plants, the time they require until they may emerge from the suffrutex stage, and the current age of the plants.

The length of the suffrutex stage is approximately 10 years (von Breitenbach 1973) but is extended by frequent fire (Vermeulen 1990). The model provides a default time of 10 years which the plant must remain in the suffrutex stage.

A For the purposes of the model a suffrutex can not grow older than 20 years

r IF a suffrutex grows older than 20 years THEN it dies

r* IF successive fires occur THEN extend the suffrutex stage by 2 years

A suffrutex may survive for a number of years under other woody vegetation, and grow if the other vegetation is removed (Boaler and Schiwale 1966).

r* IF competition is medium in the woodland frame THEN extend the suffrutex stage by one year.

r IF competition is high in the woodland frame THEN extend the suffrutex stage by 2 years.

24.3.3 The Tree Stage

The final stage extends from the time that the first permanent shoot is produced to the plant's death of old age.

A Trees have a life expectancy of 100 years (after Vermeulen 1990).

r IF a tree grows older than 100 years THEN the tree dies.

r* IF competition in the woodland frame is high for five years THEN a proportion of trees die.

Fruit are produced at age 20 (Vermeulen 1990). Since Vermeulen provides no further detail the model assumes that he is referring to 20 years after the first permanent shoot has been formed. Since the model uses a cohort approach to follow the development of the *P. angolensis* population the seed producing trees are primarily used to determine if the population may produce plants which reach reproductive maturity.

A IF a tree is older than 20 THEN seed is produced.

The correlation between size of seed crop and the degree of openness of the vegetation (After von Breitenbach 1973) was described under 'The Seed and Seedlings Stage'.

Mature trees are killed by frequent fires

r* IF successive fires occur THEN a proportion of mature trees die.

25. NECESSARY MODIFICATIONS

The sensitivity of trees to fire or canopy closure is reflected in the survival (rate) of such plants for a specific period. The most meaningful period over which survival must be measured extends from the time that plants emerge from the suffrutex

stage to reproductive maturity at 20 years. All comparisons concerning tree survival are therefore based on this period.

Due to the impact of savanna development on the younger stages of *P. angolensis* the model was modified to investigate tree survival. Instead of introducing a new cohort of seed at the start of every year in the simulation, a cohort of saplings was introduced. This simplified the interpretation of the model significantly.

26. MODELLING PROCEDURES

26.1 The Savanna Model

Initial simulations indicated that the number of *P. angolensis* seed produced by the model is strongly related to the time that the simulation remained in the grassland frame. The time that the model requires to reach woodland status, was therefore considered highly significant.

The mean time to woodland was also considered to be a measure of the combined effects of the factors which affect savanna grassland development. To investigate these influences one thousand runs of a maximum possible time of two hundred years were run for each of three levels of the factors under consideration, and for five percent intervals in the probability of fire from zero to one hundred.

Each simulation was initiated at the lowest competition level in the grassland frame and run until it reached woodland status. The time was then recorded. At the end of one thousand simulations a mean was calculated for those runs which reached woodland status at each probability level.

For extreme settings woodland status was not reached by all iterations within the two hundred year limit of the model. To facilitate comparisons only those repetition where 990 iterations or more reached woodland status were used in the evaluation, as indicated above.

The development of the woodland frame was investigated in a similar manner; the model was initiated in the lowest canopy class rather than in the grassland frame. The mean time to full canopy closure (canopy class 5) was taken as the measure of interest.

26.2 The *P. angolensis* Model

26.2.1 Suffrutex Survival

The development of suffrutex survival must be viewed in terms of the model algorithms as follows: The model evaluates the cumulative effect of fire by summing the 'heat' of fires over the last few years (a maximum of five years), but independently of fuel loads. Once the total heat exceeds a tolerance threshold the suffrutex stage is extended by a year.

Since the model limits the survival of plants in the suffrutex stage to a maximum of 20 years, repeated extensions in the time that the plant requires to reach sapling state eventually result in the death of the plant.

To investigate the development of *P. angolensis* through the suffrutex stage the effects of a number of factors which influence suffrutex survival were simulated. The effects of changes in model parameters were measured in terms of the proportion of the plants entering the sapling stage.

26.2.2 Tree Survival

Apart from using the modifications to the model as described above, the effect of fire on tree survival was evaluated by accumulating the intensity of fires over a specified interval and comparing the periodic total to a given threshold value. When the threshold was exceeded, a proportion of trees were removed from the model.

The effect of canopy closure on tree mortality was investigated in a similar manner.

27. EVALUATION OF THE MODEL

The evaluation of the savanna and the integrated *P. angolensis* models was based on the interpretation of graphic output. Due to the IF-THEN-rule based nature of the two models the magnitude of the variables in the model is of lesser importance

than the relationship between variables. Similarly, the interpretation of the graphs rests on qualitative differences rather than on the comparison of actual values.

27.1 Fire Occurrence

Before the evaluation of the model commenced the relationship between the probability with which a fire would occur and the actual occurrence of fire was investigated. To do so, 1000 iterations of 200 years were run and the number of fires counted. This method not only provided an indication of the sought after relationship but also provided an indication of the variance of fire occurrence for a given probability of fire.

Comparisons between the fire probability and actual occurrence of fires were made at intervals of 5% probability from 0% to 100%. The resultant relationship is indicated in figure 10.

The graph shows that the frequency with which a fire occurs is directly proportional to the fire probability. On the other hand, the graph clearly indicates that the variance of the fire frequency changes with changing fire probability.

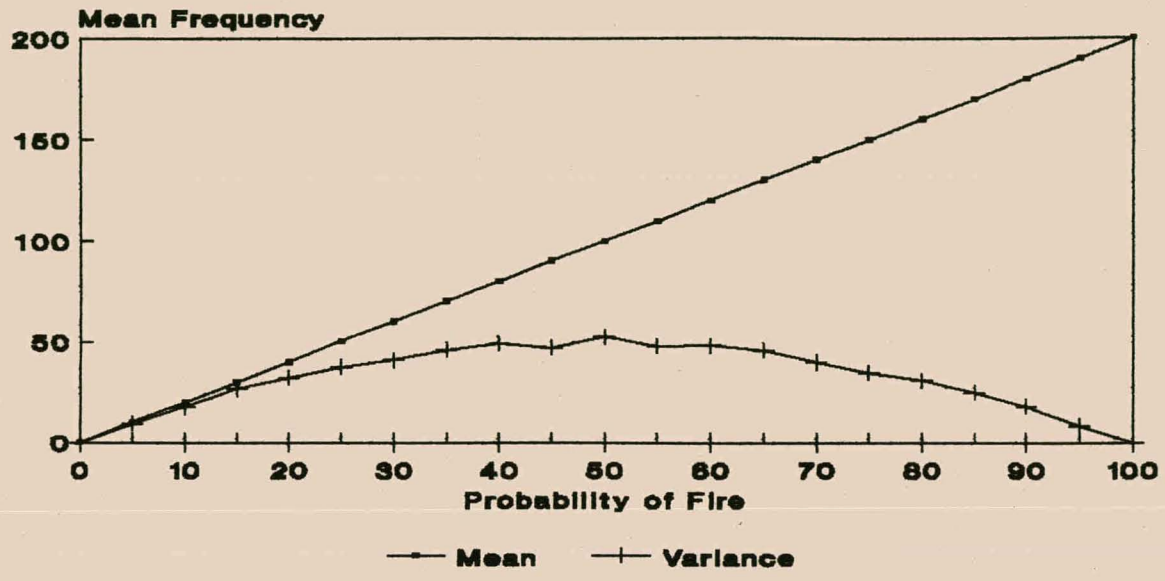


Figure 10. The relationship between the probability of fire and the mean number of actual occurrences, based on 1000 simulations of 200 years.

The variance shows an increase in the lower fifty percent of the probability of fire to reach its maximum at fifty percent. The variance subsequently decreases to reach zero at 100 percent probability.

The low variance shown during the initial stages of the graph are a result of the greater portions of 'no fires' as opposed to the exact opposite at higher probabilities.

Figure 11, on the other hand, shows the relationship between the probability with which a fire may occur, and the mean time

between actual fires. The graph shows, that the time between burns decreases sharply as fire probability increases.

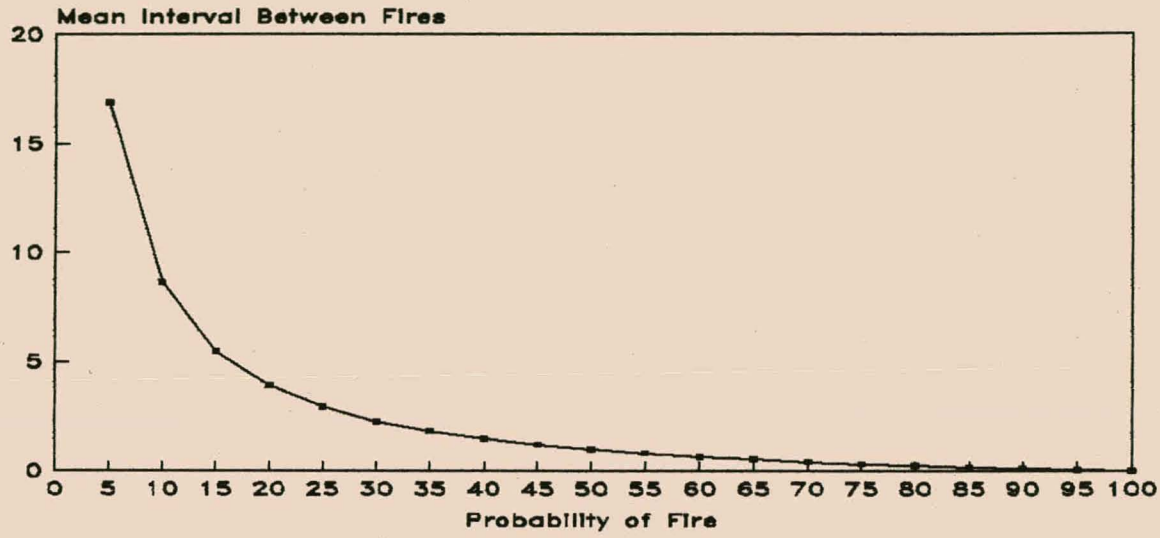


Figure 11. The relationship between the probability of fire and the mean intervals between actual occurrences of fire.

27.2 Fuel Load Development

The results of the simulations investigating the development of the fuel load under low, medium and high fuel accumulation rates are provided in Figure 12. During the simulations the amount of fuel which was able to accumulate between fires was recorded and the average was calculated for each fire probability level. All simulations were initiated at the lowest competition level in the grassland frame.

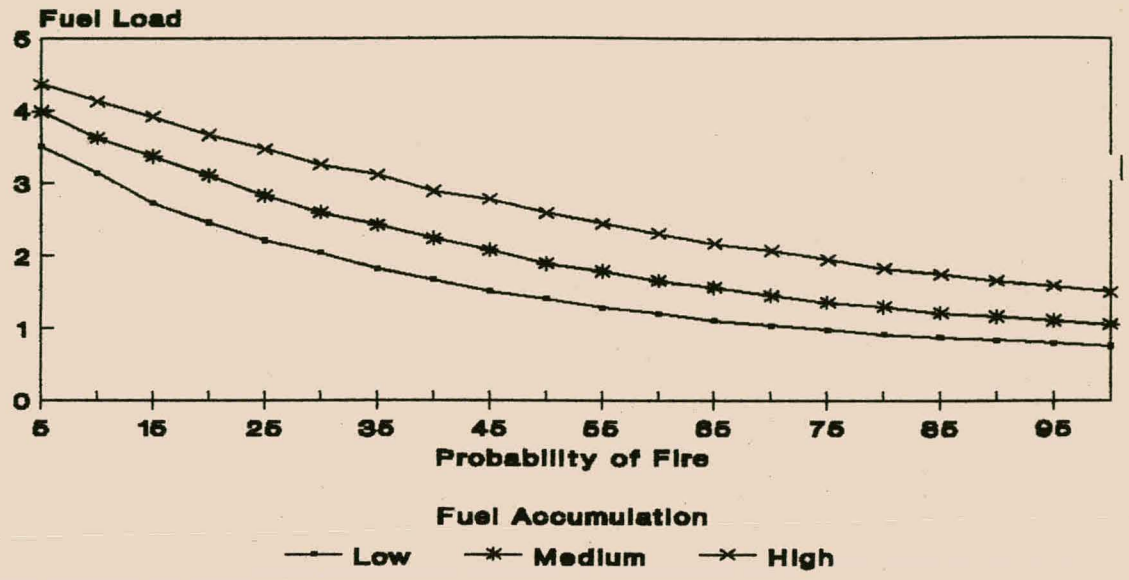


Figure 12. The development of the mean fuel load between fires subject to low, medium and high fuel accumulation rates.

The development of the fuel load is important since the model assumes that fire intensity is linked to the fuel load. Considering the development of the fuel load, fires at low fire frequency are on average hotter than at higher frequency. As a consequence the ability of the vegetation to develop is dictated by its ability to absorb fire damage and to recover to pre-fire levels.

27.3 Mean Time to Woodland In the Savanna Frame

27.3.1 The Effect of Fire Frequency

The effect of fire frequency was investigated by considering the mean time to woodland in relation to the probability of fire.

Repetitions with different fuel accumulation rates and damage to the vegetation as a result of fire indicated that fire frequency cannot be viewed in isolation.

27.3.2 Fuel Load Accumulation Rates

The effect of fuel load accumulation rates was investigated in conjunction with changes in fire frequency. The results are given in Figure 13.

As fuel accumulation rates decrease the rate of increases in mean time become very much less pronounced.

On the other hand, if fuel load is able to increase rapidly the mean time will not stabilize, given the time limit of the simulation. Rather, the vegetation is unable to reach the woodland frame at all.

The effect of fuel accumulation is concentrated primarily on the medium and high fire frequencies.

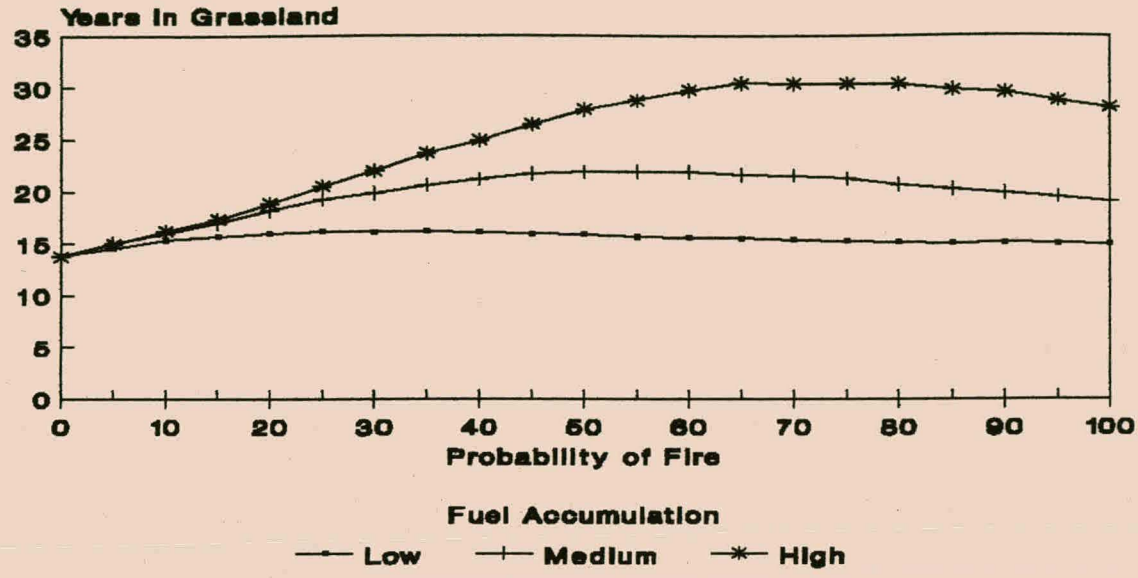


Figure 13. Comparing the effect of three levels of fuel load accumulation on the average time that the model remains in the grassland frame. Low, medium and high accumulation rates are 0.5, 1.0 and 1.5 respectively during low rainfall years, and double the amounts for high rainfall.

Further investigations showed that fuel load development plays a key role in the relationship between fire damage, fire frequency and the mean time to woodland.

27.3.3 Decreases in Vegetation Cover due to Fire Damage

The importance of damage to the vegetation was also investigated in conjunction with fire frequency, and the results compared graphically in Figure 14.

At low fire damage the mean time to woodland increased rapidly to reach a maximum at a fire probability of 0.35. Mean time then decreases with increasing probability of fire.

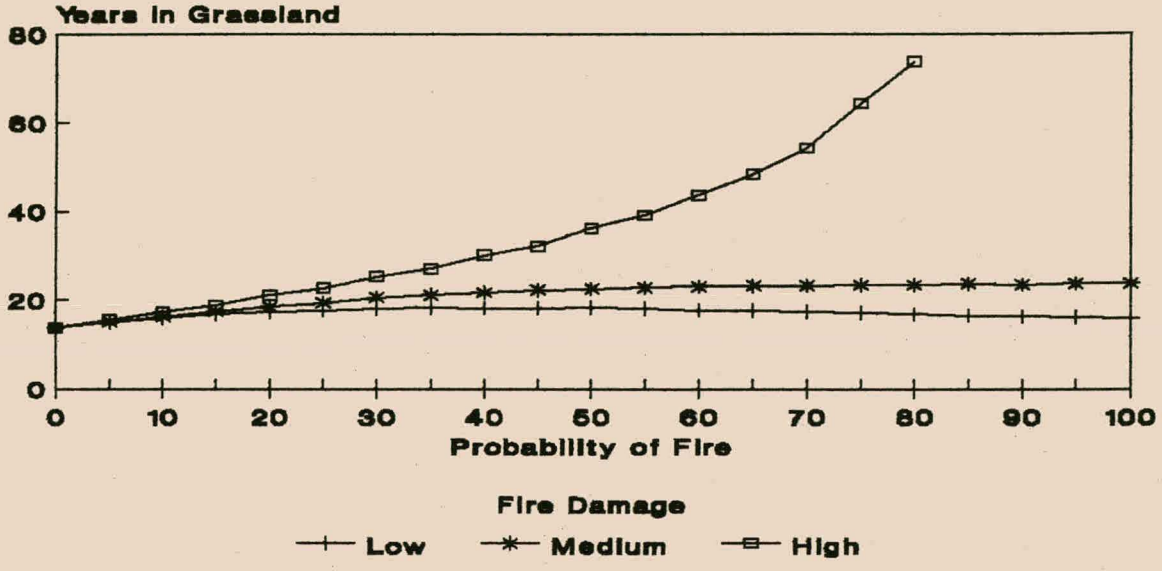


Figure 14. Comparing the effects of three levels of damage on the mean time that the simulation remains in the grassland frame.

For medium damage the vegetation the mean time to woodland increases sharply with increasing fire frequency. Mean time then stabilises at 0.35 fire probability and little further increase in time occurs.

For extreme settings in damage rates there is a sharp increase in time until 0.8 fire probability. After this point the simulation rarely reaches woodland status.

27.3.4 Damage to Vegetation due to Hot Fires

Damage by hot fires was investigated by reducing damage rates at lower fuel loads to zero, and increasing them for the higher fuel load classes. Damage rates by less intense fire was subsequently increased. The results of the simulation are given in Figure 15.

If only those fires which burn high fuel loads cause reductions in the height of the grassland, then woodland status is reached much sooner than under conditions where the burning of low loads also cause significant damage. This difference is especially visible when the probability of fire is high.

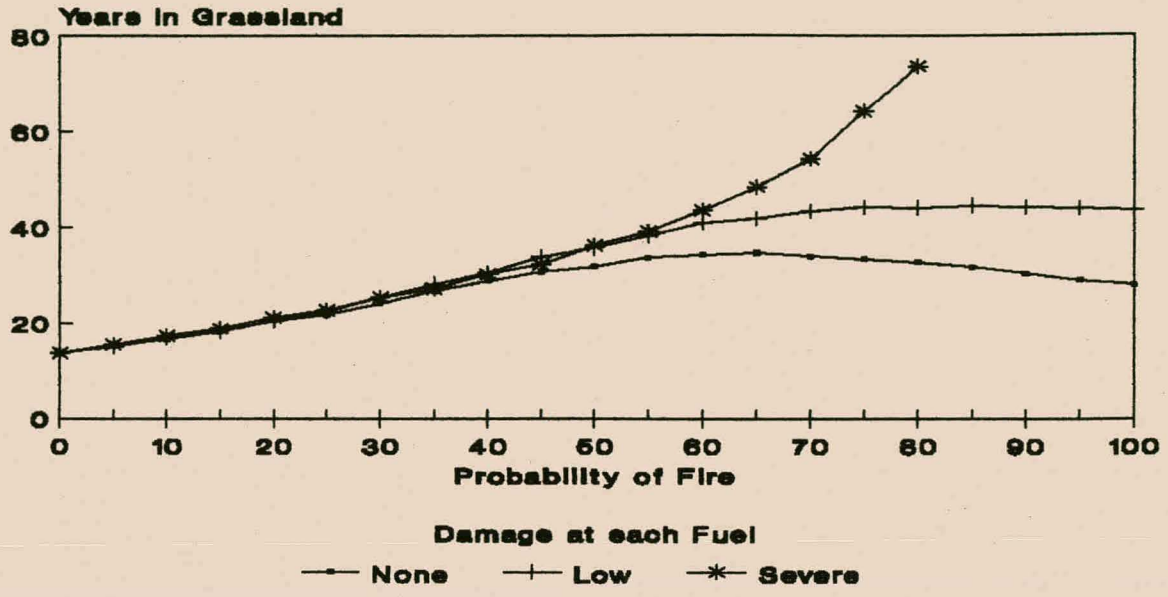
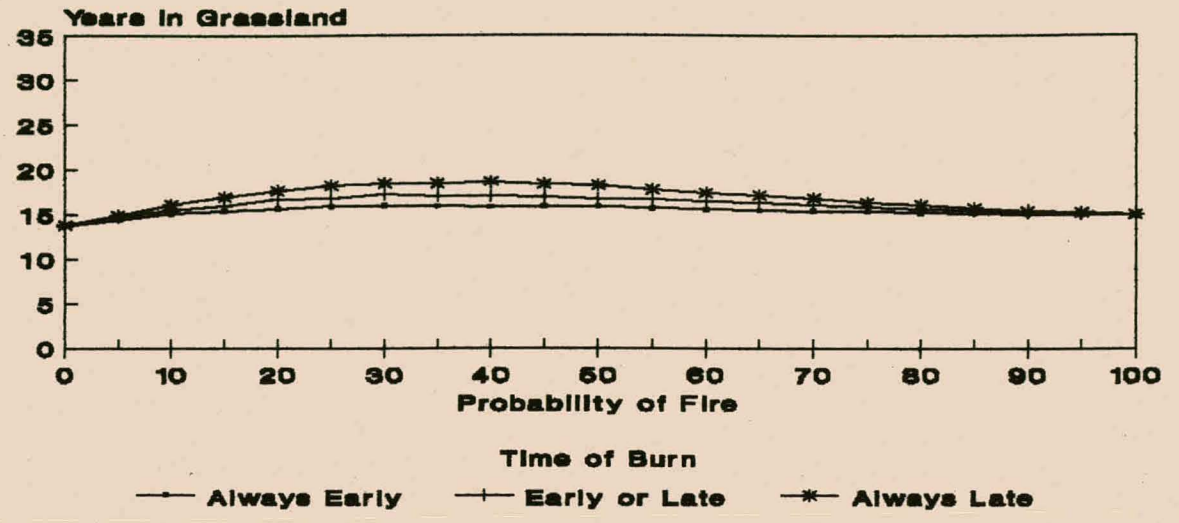


Figure 15. The effect of damage caused by fires which consume low fuel loads, on the mean time that the vegetation remains in the grassland frame. Three levels are compared.

27.3.5 The Effect of Fire Season

To determine the effect of fire season one thousand iterations of 200 time steps were run respectively for early burning only, late burning only and equal likelihood of early or late burning. The resultant means were calculated and are depicted in Figures 16a and 16b.

a)



b)

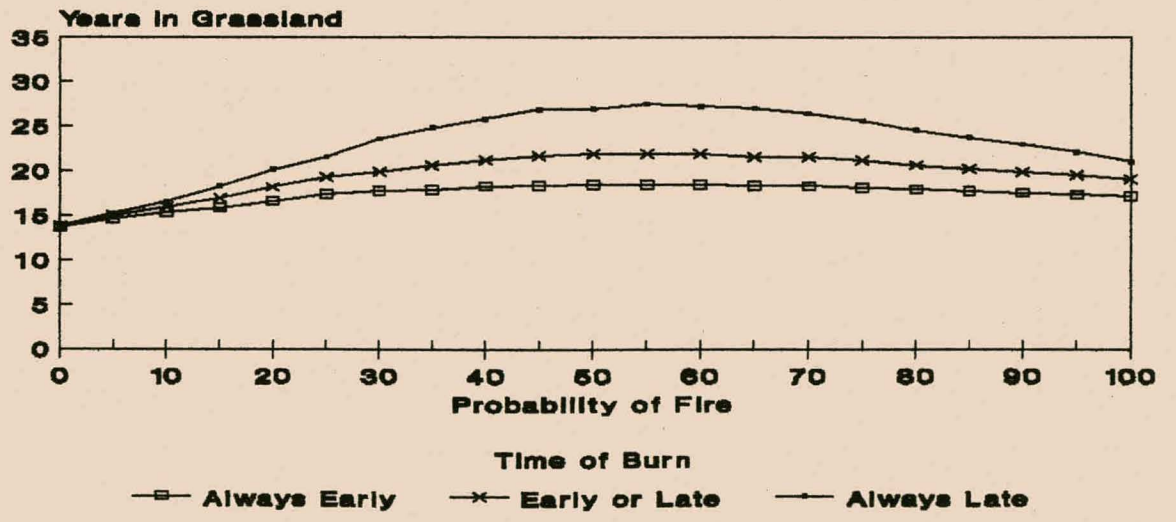


Figure 16. The effect of the timing of a burn on the time that the vegetation remains in the grassland frame. The graphs compare burning under the influence of (a) medium and (b) high fuel accumulation rates.

Figure 16a shows that implementation of early burning reduces the average time that the savanna requires to reach woodland status. Random early or late burning results in longer periods while late burning requires the longest time.

Further investigations showed that this effect is enhanced by fuel load development. High fuel load accumulation rates accentuate the differences between the times of burning. These differences are apparent when figures 16a and 16b are compared.

27.3.6 Effect of Growth Rate

Figure 17 shows that high growth rates suppress the initial, rapid increase in mean time to woodland, which was previously associated with low fire frequencies.

As growth rate is reduced, the mean time increases with increasing fire frequency, but the vegetation is still able to reach the woodland frame.

To determine the influence of the growth rate settings in relation to the damage caused by fire a number of simulations where both fire damage and height growth were increased were run. The resulting graphs of the mean time to woodland vs. fire probability showed, that the influence of each of the two factors dominates at different fire frequencies. See also Figure 14. for comparison.

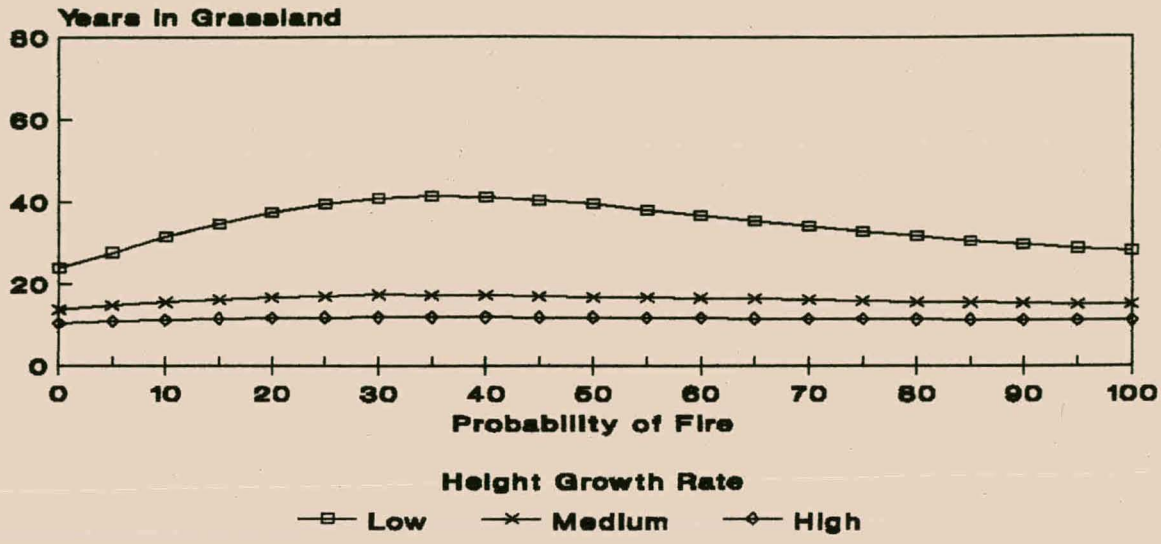


Figure 17. The average time that the model remains in the grassland frame, subject to low, medium and high savanna growth rates, and in the presence of increasing fire frequency.

When the damage caused by hot fires is high and cooler fires cause less damage, influences are primarily visible at higher fire frequencies.

At lower frequencies the growth rate dominates development. On the other hand at very high fire frequencies the difference between the damage to the vegetation and the growth rate is most important.

27.4 Mean Time to Full Canopy Closure in the Woodland Frame

The time required for the savanna to attain full canopy closure is dependent on a combination of the factors which affect the woodland development. To evaluate the significance of each of these factors the model was initiated in the lowest form of the woodland frame, with canopy closure in class 2, and ended once the woodland had attained a closed canopy (class 5).

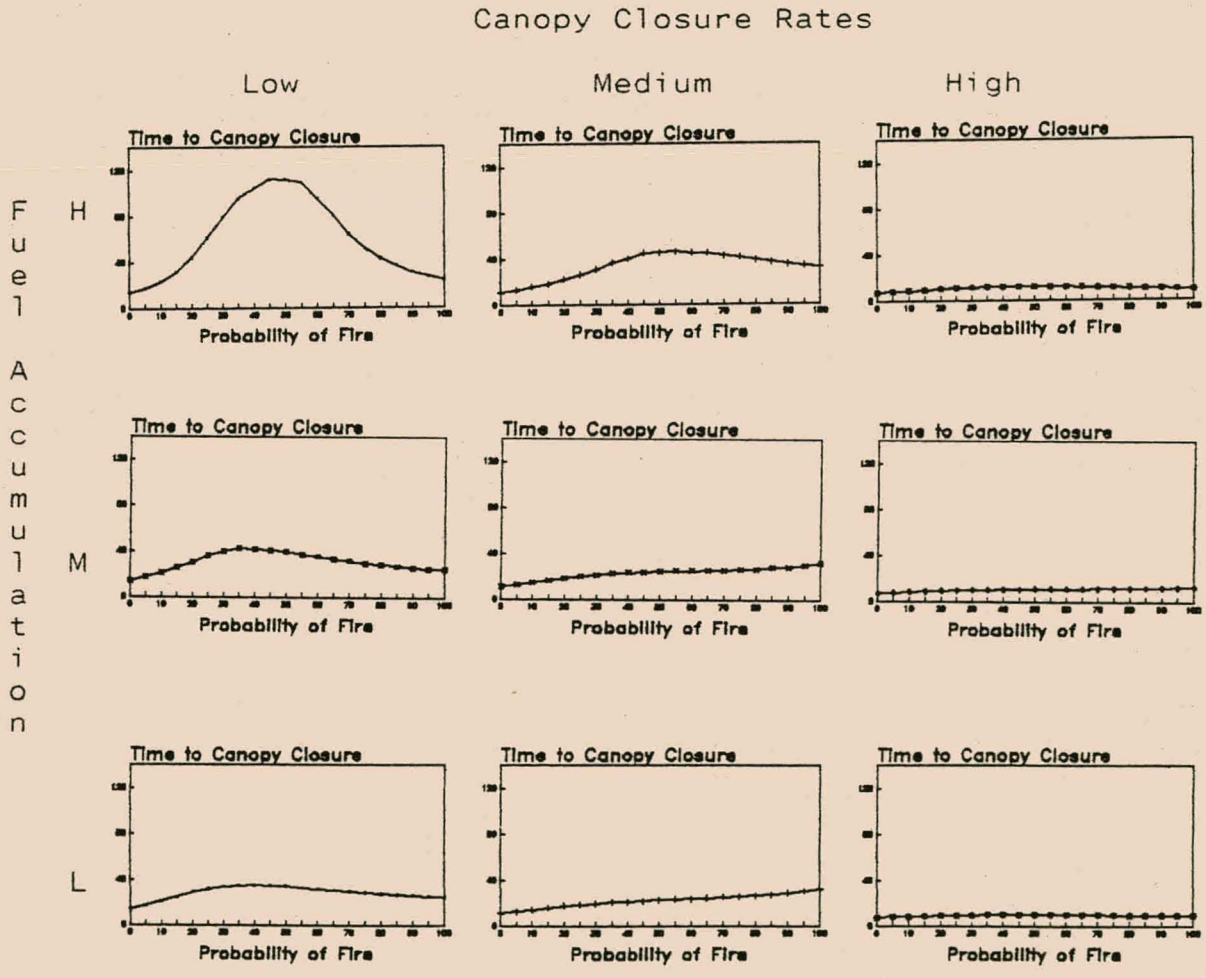


Figure 18. The relationship between fire frequency and the mean time to full canopy closure for changes in fuel accumulation rates and changes in canopy closure.

The mean time to total canopy closure in relation to fire frequency follows the same trend as the mean time to woodland of the grassland frame. The effect of changes in fuel accumulation and canopy closure rate are shown in figure 18.

The similarities in the development of the two vegetation types are primarily due to the similarities between the algorithms which simulate them, and reflect the balance between the growth of the vegetation and the damage inflicted upon it.

27.5 The *Pterocarpus angolensis* overlay

27.5.1 Seed Production

Initial simulations indicated that the amount of seed produced is closely linked to the time that the model remains in the grassland frame.

To obtain further evidence of this relationship the effect of savanna height growth and fuel accumulation on seed production was investigated. Figure 19 shows similar trends to those of grassland development in the presence of changing fuel accumulation and height growth. (See Figures 13 and 17 for comparison)

According to the graphs in Figures 13, 17 and 19, an increase in the mean time to woodland due to manipulation of the influencing factors coincides with an increase in the total amount of seed produced.

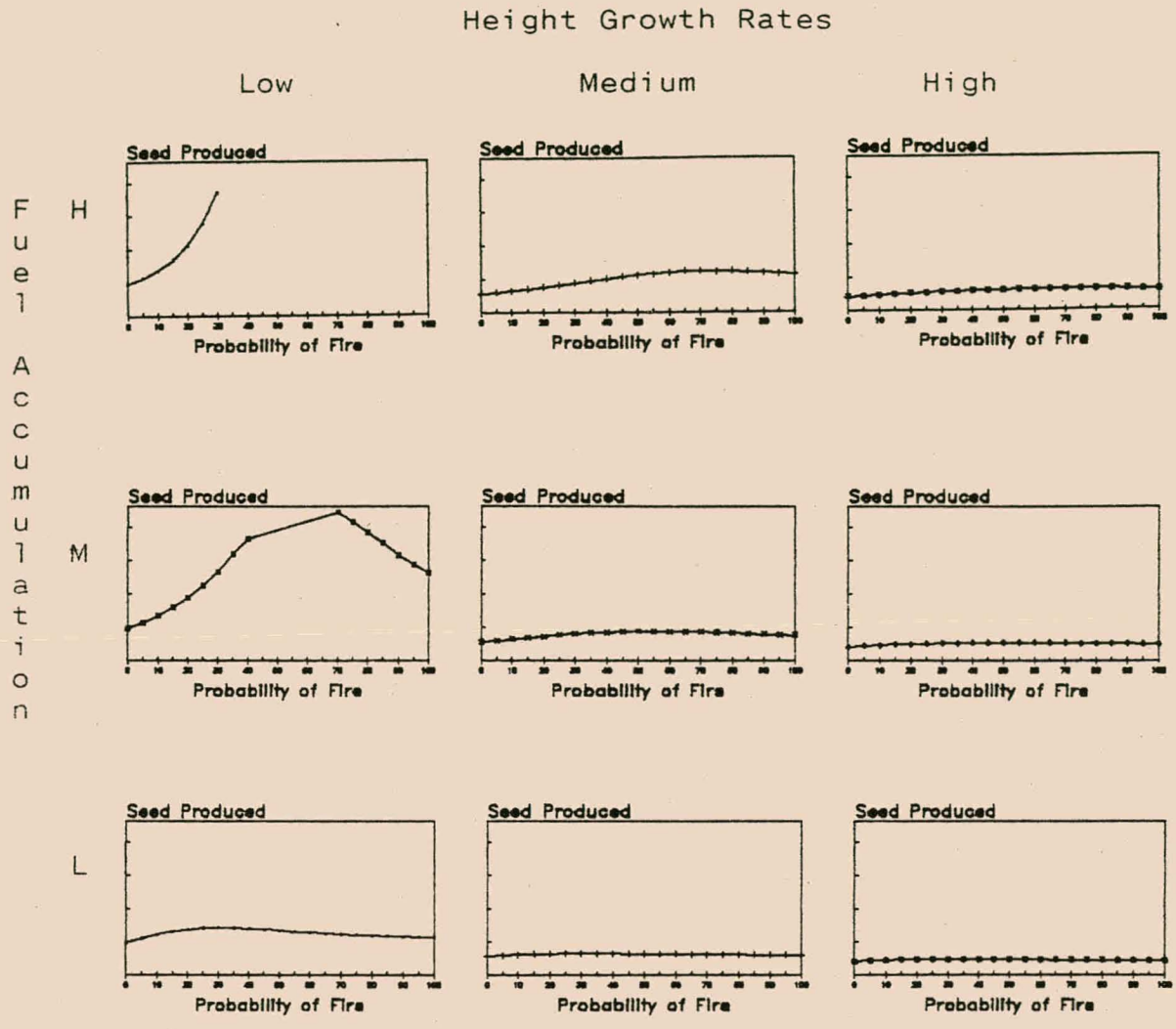


Figure 19. The amount of seed produced in the grassland frame while the grassland is subjected to a) different fuel accumulation rates and b) savanna height growth rates.

A similar relationship was found to exist between seed production and the time to canopy closure in the woodland frame. The amount of seed produced in the woodland is generally lower due to competition with the surrounding vegetation - as defined by the model.

27.5.2 Seed Germination and Seedling Establishment

Figures 20a and 20b show the relationship between the total number of established seedlings and the effect of fuel accumulation and height growth respectively (See also figure 13 for a comparison). Figure 21 depicts the proportion of seed which may germinate in a given year in response to changes in fire frequency.

As fire frequency increases, the corresponding decline in the average fire intensity leads to an increase in the average proportion of seed germinating.

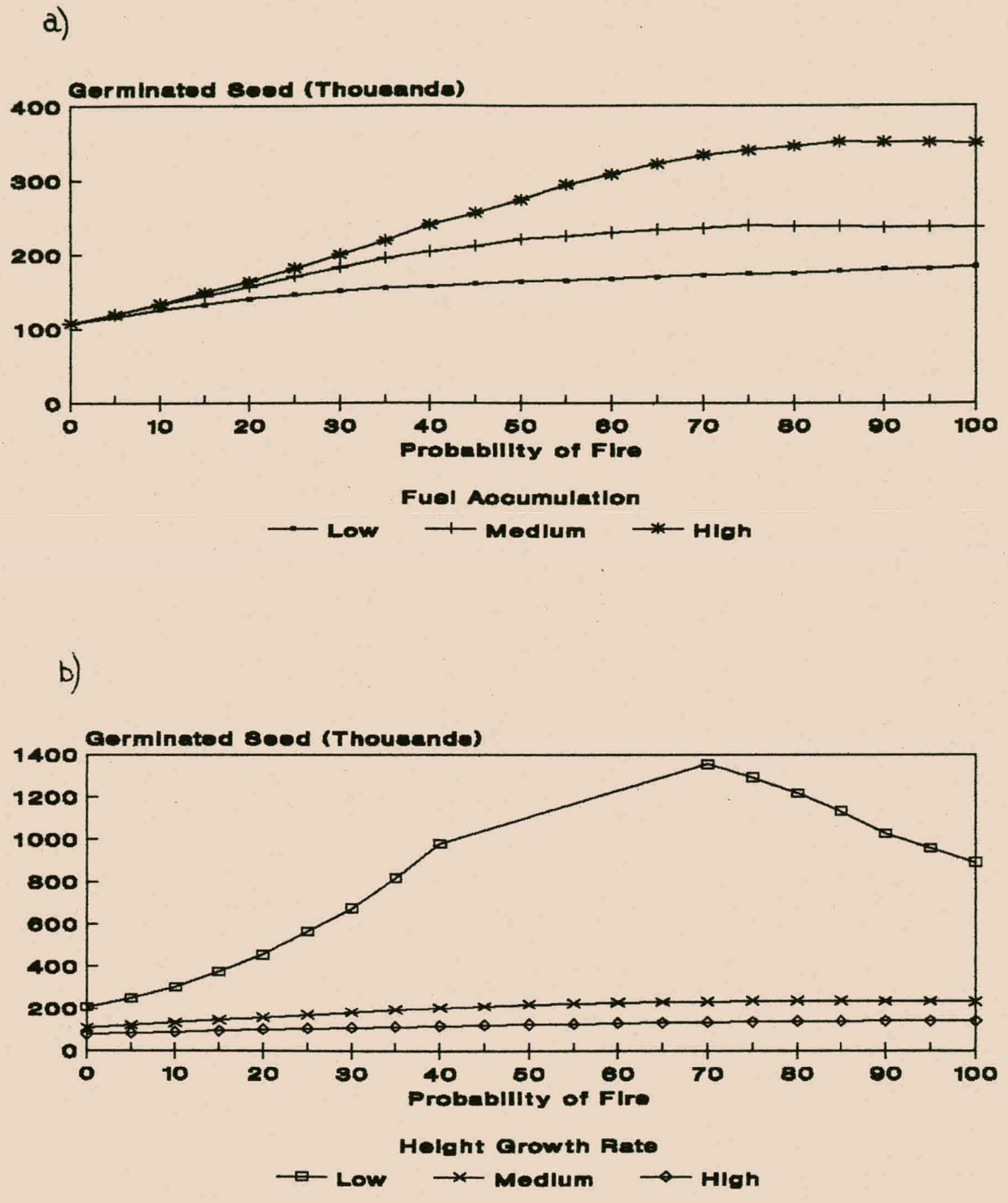


Figure 20. The effect of a) fuel accumulation, and b) height growth rate on the number of seed which germinate in the grassland frame.

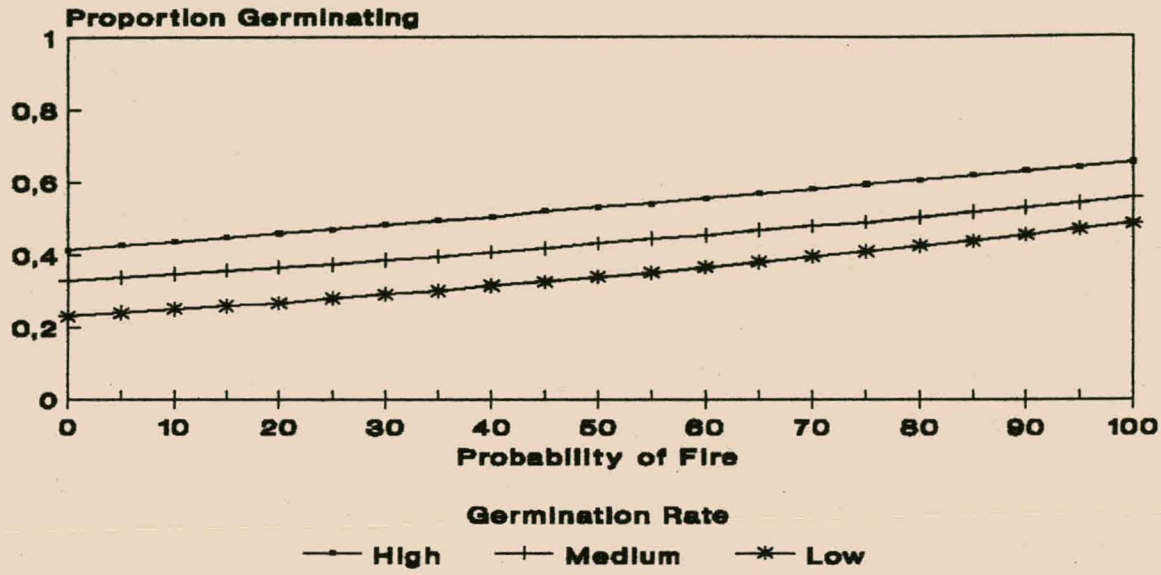


Figure 21. The proportion of seed germinating in response to changes in fire frequency. The three graphs show the effect of three levels of germination rates.

The trend of seedling establishment in the woodland frame is once again similar to that in the grassland frame. However, due to the lower seed production in the woodland frame the total number of established seedlings is much lower.

27.5.3 Suffrutex Survival and the Establishment of Saplings

This section evaluates the effect of a number of factors on the survival rates of suffrutex plants in the grassland frame. The factors which were investigated are fuel accumulation, the time of burning, height growth and the sensitivity of suffrutex plants to fire damage and to competition.

The results of these simulations are provided graphically in Figure 22, Figures 23a and 23b and Figure 24

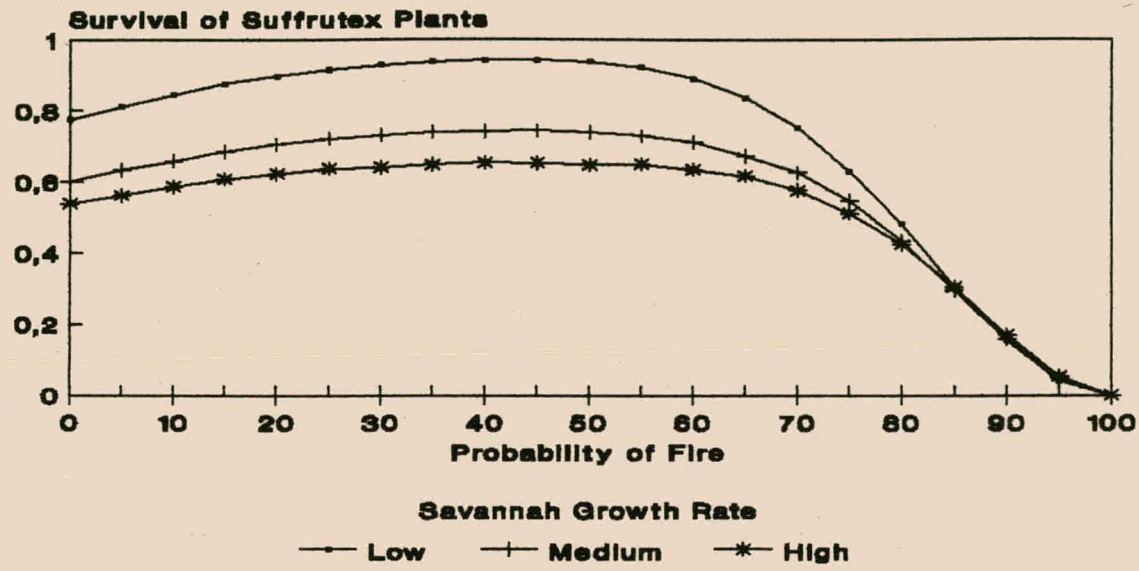


Figure 22. The effect of change in savanna height growth on the number of suffrutex plants which reach the sapling stage.

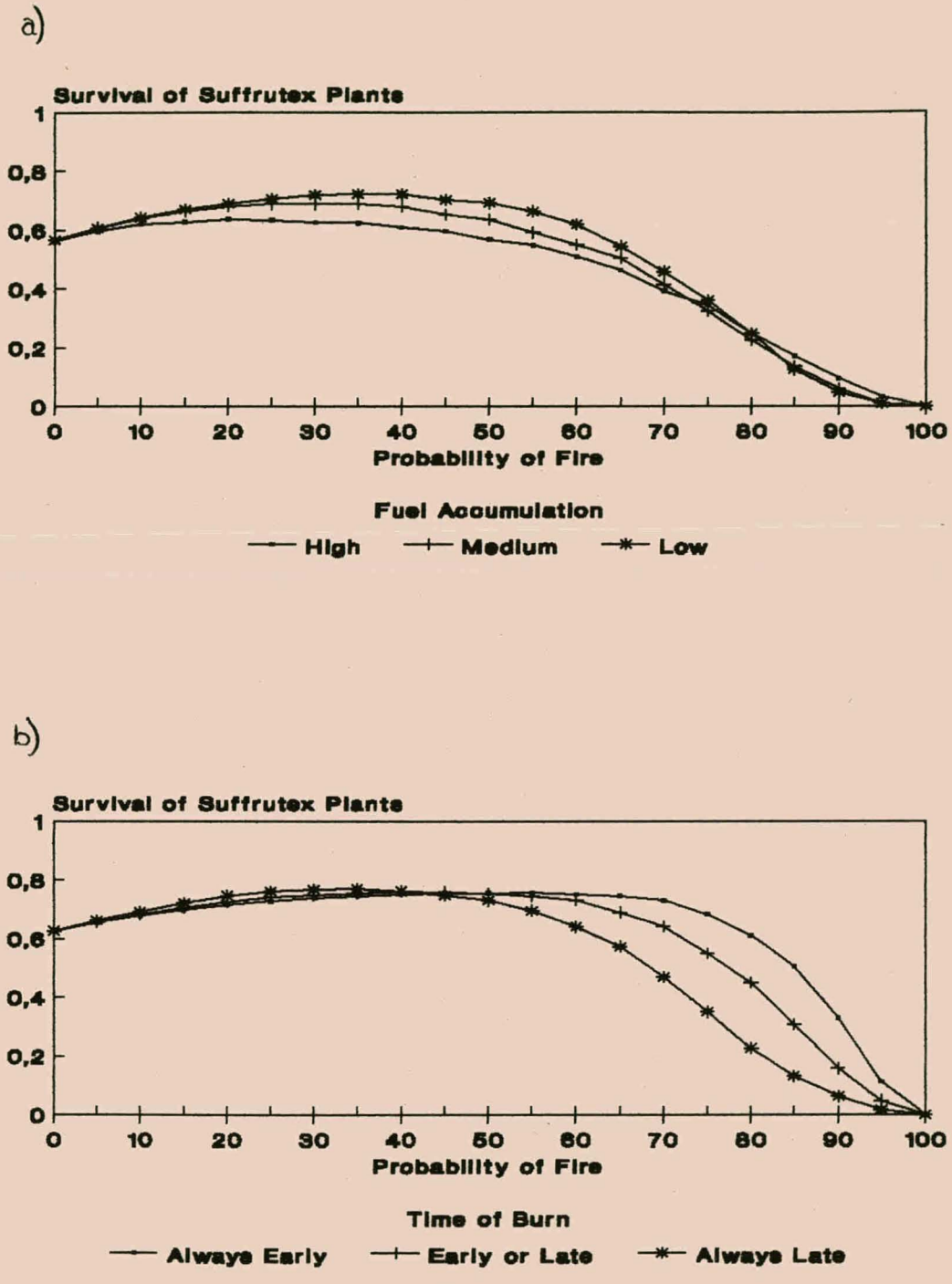


Figure 23. The relationship between suffrutex survival in the grassland frame and fire frequency, influenced by a) fuel accumulation rates, and b) time of burning.

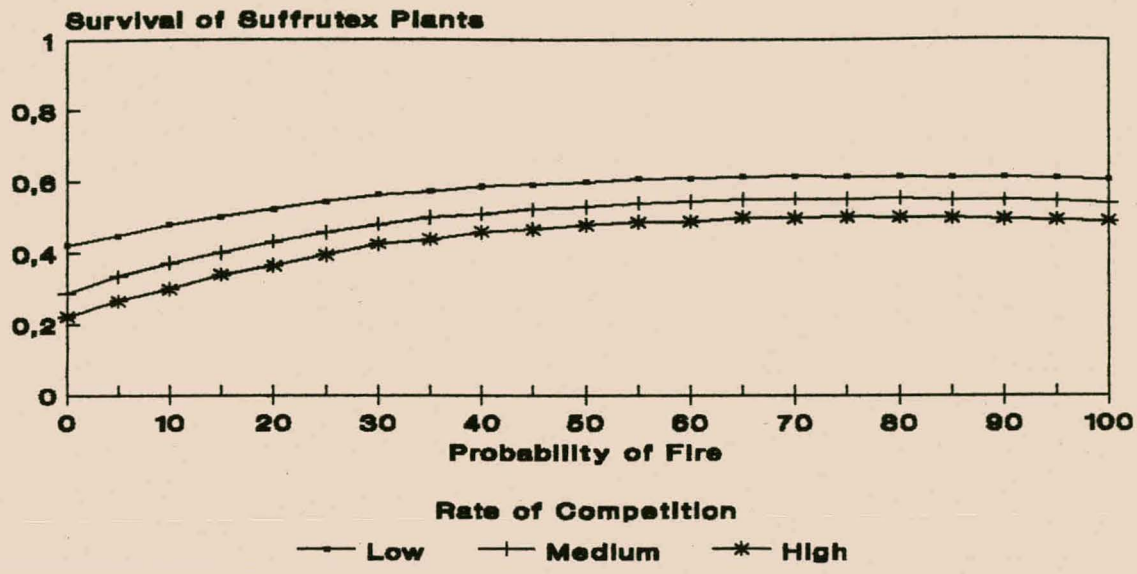


Figure 24. The survival of suffrutex plants subject to three levels of competition in the presence of increasing fire frequency.

Figure 22 as well as Figures 23a and 23b show that suffrutex survival increases slightly with fire frequency, while the probability of fire remains below 50%. Once this threshold is exceeded the proportion of surviving plants starts to decline.

The greatest differences are visible in Figure 22, where survival as a whole is reduced as savanna growth rate increases. On the other hand, Figure 17 indicates that the time required by the savanna to develop to woodland status is reduced if grassland height growth increases. Therefore, while

the savanna develops rapidly suffrutexes have to cope with a higher degree of competition as a whole.

27.5.4 Survival of Trees to Maturity

The effects of fire damage and competition on the survival of trees to reproductive maturity were investigated. The results of the simulations are provided in Figures 25a and 25b. To assist with the interpretation of the graphs, the parameter settings for the simulations are provided in tables 14 and 15.

Table 14. Parameter settings to investigate the sensitivity of *P. angolensis* trees to fire damage. The first line in the table is interpreted as follows: If cumulative fire intensity exceeds 6 within five years then mortality occurs. The mortality rate in turn is determined by the fuel load of the latest fire.

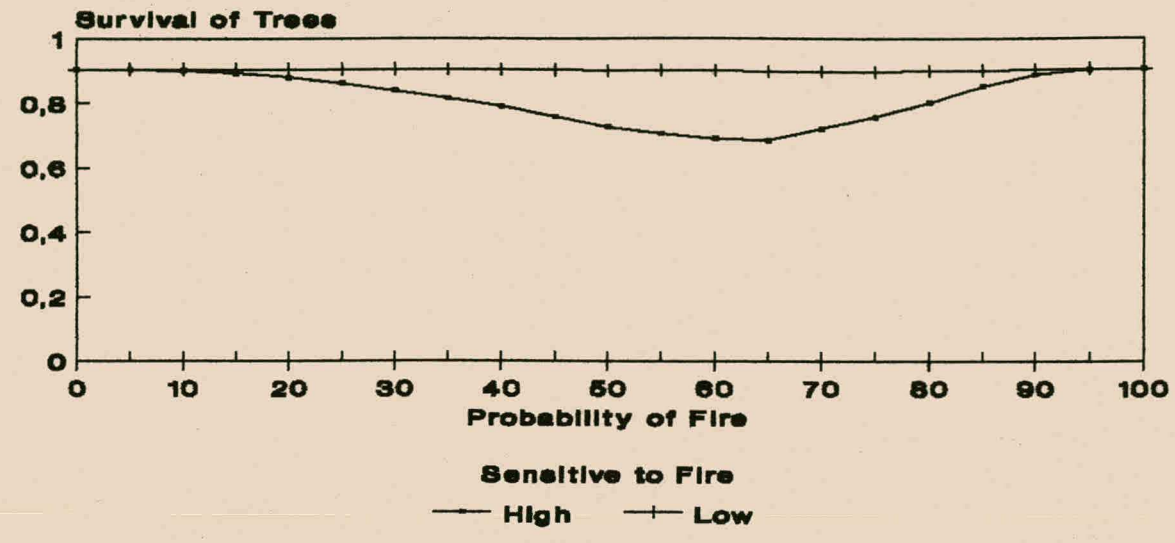
Sensitivity	Cumulative Fire intensity	Period
Low	6	5
High	3	3

Table 15. Parameter settings to investigate the sensitivity of *P. angolensis* to canopy closure. The first line in the table is interpreted as follows: If cumulative canopy closure exceeds 29 within 5 years then there is a 20% mortality of trees.

Sensitivity	Cumulative Canopy Closure	Period	Mortality
Low	29	5	0.2
Medium	27	5	0.2
High	20	5	0.2

The graphs show that the susceptibility of the population to fire damage is most important at medium fire frequencies. Conversely, a high degree of tree survival is experienced when frequencies are very low or very high. This trend is a result of the interaction between fire frequency, fuel load development and fire intensity.

a)



b)

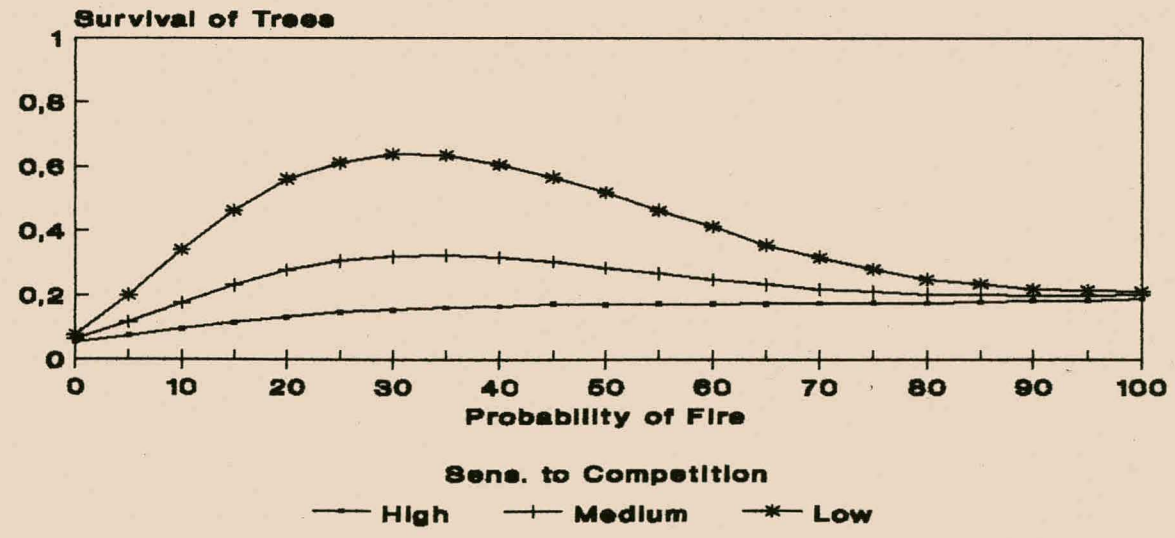


Figure 25. The survival of trees subject to their sensitivity to a) damage by fire, and b) canopy closure.

27.5.5 Comparing the Effect of Fire on Development

In order to determine differences in management requirements for the different developmental stages of *P. angolensis*, the effect of fire on the different stages was compared. The model was initiated in the grassland stage, and continued until the woodland stage was reached.

The fire regimes were based on fuel load. A fire occurred only once a given fuel load class was reached. The graph in figure 26 shows the survival rates of plants under the burning regimes based on fuel load classes from 1 to 5.

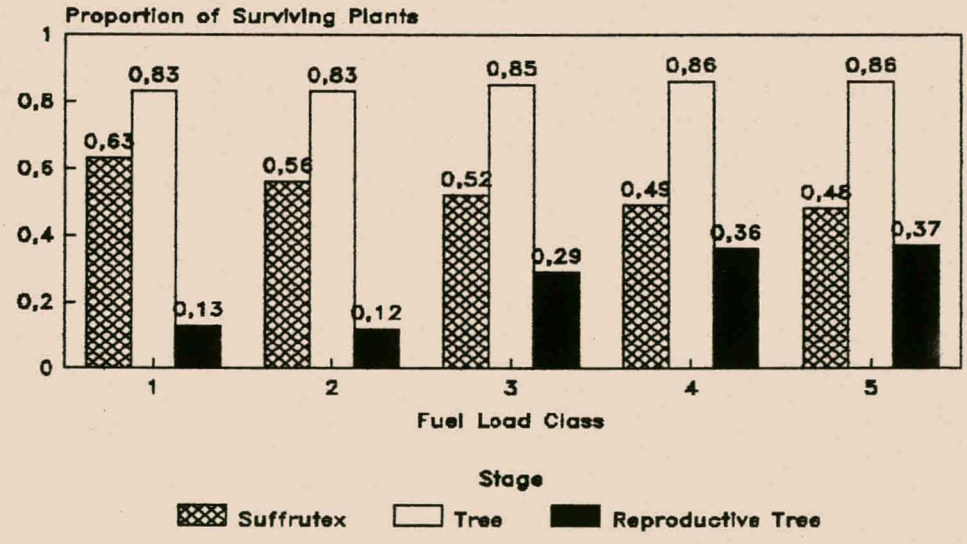


Figure 26. The effect of fuel load based burning regimes on the survival of *P. angolensis* plants.

Figure 26 shows that the tested regimes affect the different stages of plant development differently. While the establishment of suffrutex plants is highest at a low fuel load based fire regime, the survival of suffrutex plants to the tree stage is higher at higher fuel load induced fires.

28. DISCUSSION

28.1 Savanna Vegetation Development

During the evaluation of the model it became evident that both the occurrence of a fire and the non-occurrence of fire have strong implications for the development of the savanna. While a fire reduces vegetation cover, the period between fires permits plant development. The same periods, however, also permit the accumulation of fuel which in turn affect the amount of damage inflicted on the vegetation with the next burn.

The results provided by the model imply that the periods between fires and the associated fuel development are of greater importance for the savanna than the occurrence of the fire itself. The eventual burn merely causes the damage dictated by the accumulated fuel. The magnitude of the impact depends on the resilience of the vegetation.

In general, three basic states of final vegetation may be identified at the end of a 200 year simulation. These states are as follows, given that the simulation is initiated in the grassland frame:

Permanent Grassland:- occurs when the damage caused by fire to the savanna is so great that the vegetation is unable to recover before the next burn.

Permanent Woodland:- occurs when the savanna is able to develop through the grassland and woodland frames. In this case fire damage to the savanna is less than grassland height growth or woodland canopy closure.

Fluctuation between Grassland and Woodland:- occurs when conditions are favourable for the vegetation to develop beyond the grassland frame, while conditions are unfavourable for canopy development.

The parameters which determine the reductions in savanna height or canopy cover as a result of fire represent the resistance of the vegetation to fire damage. On the other hand, the parameters which govern growth rate represent the rate at which the vegetation recovers after fire, as well as its capacity to develop from one level of vegetation to the next. Vegetation hardiness and growth rate take effect at different fire frequencies.

According to the model the effect of change in fire frequency on vegetation development depends on the resistance of the vegetation to the subsequent fire intensity, and on the ability

of plants to recover between burns. A lower fire frequency will, for instance, lead to a higher intensity of the average fire. If this intensity exceeds a certain (damage) threshold value the vegetation may deteriorate rather than develop towards a closed woodland.

On the other hand an increase in fire frequency results in a lower average fire intensity. This in turn may favour development towards closed woodland status. The simplified relationship between the fire interval and the intensity of fires is provided in Figure 27.

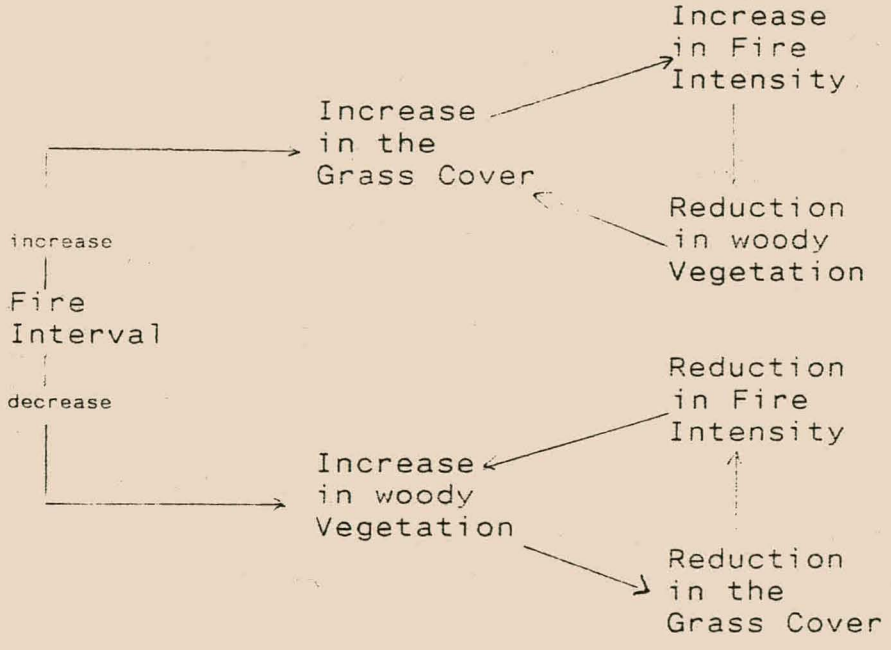


Figure 27. The relationship between fire interval and the intensity of fire.

Generally, the resistance of the vegetation to fire and rate of growth between fires determines the ability of the vegetation

to maintain or reach any level of development under a given fire regime. The same factors also influence the time it takes to develop from one level to another.

More specifically, however, the two factors (resistance to damage, and recovery rate) determine the ability of the vegetation to develop from grassland to woodland status. Once the woodland state is reached these factors determine the ability of the vegetation to maintain this status or to develop towards total canopy closure.

According to the model regular late burning retards the development of the savanna. Regular early burning on the other hand allows the model to reach woodland status much sooner. This trend is a direct consequence of the difference in fire intensity which the model associates with the different seasons, and the consequent damage to the vegetation.

28.2 P. angolensis development

28.2.1 Seed Production

The simulations showed that the amount of seed produced by the model is very closely related to the time that the savanna requires to reach woodland status.

Total seed production is therefore enhanced by those factors which promote an open vegetation, or which retard the development of the vegetation to woodland status. The model

shows that savanna growth may have particularly significant effects.

These results are in concert with the findings of von Breitenbach (1973) who reported heavy fruit crops particularly in open areas. The seed crop is reduced, however, by the competition from the surrounding vegetation.

28.2.2 Seedling and Suffrutex Establishment

The total number of seeds which are able to germinate while the system is in the grassland frame is dependent on the development time to woodland status, as well as the germination rate each year. This total is affected by the effect of fire on the germination rate of seed itself.

The factors which retard savanna development therefore result in an increase in the total production of seed. It must be kept in mind, however, that while fire may retard savanna development it may also cause some mortality to seed producing trees and cause subsequent decreases in seed production. Due to the cohort approach this effect of fire cannot be tested directly.

According to the model, annual seedling establishment is highest when annual fires occur, but the total number of seedlings produced in a simulation is less than at lower fire frequency since the mean time to woodland is reduced.

From figures 20 and 21 it is apparent that the rules which link fire intensity and germination rate take effect at different fire frequencies. Figure 12 showed that mean fuel load is higher at low fire frequencies. Since high fuel loads always cause hot fires especially when burns are late, germination is mostly low in the presence of fire while burns are infrequent.

The effect of rainfall on seedling establishment was investigated by manipulating the establishment rates since seedling establishment is closely related to rainfall. The results showed that the increased rates resulted in an higher percentage of seedlings entering the suffrutex stage.

28.2.3 Suffrutex Survival

The overall survival of suffrutex plants is strongly affected by fire intensity. This is reflected in the relationship between fuel accumulation and plant survival. According to the model suffrutex survival at medium fire frequencies is high. Subsequent increases in fire frequency, on the other hand, increase mortality rates.

Further simulations indicate, however, that the time of burning has a visibly greater effect on suffrutex survival than fuel accumulation. The model assumes that early burns are always of low intensity, reducing the impact of fire on the plants.

The results of the model also indicate that plant mortality due to fire damage and competition takes effect at different fire frequencies. While the sensitivity of the suffrutex to fire predominates at higher fire frequency, the importance of competition becomes greater at low fire frequency, when vegetation development is faster.

28.2.4 Tree Survival

Tree survival in response to competition and damage by fire take effect at different fire frequencies. The model showed that where plants are less exposed to fire damage due to lower fire frequencies, they are increasingly susceptible to mortality caused by competition caused by an increase in plant cover.

Although the heavy fuel loads associated with low fire frequencies cause more intense burns, trees are able to recover before the next fire occurs. As fire frequency is increased the repeated occurrence of fire overcomes the resistance of trees and mortality occurs. The severity of fire damage increases with fire frequency, but later declines as fires prevent fuel build-up.

PART 7. DISCUSSION

29. SAVANNA MANAGEMENT

The review of the literature, the enumeration of a section of woodland vegetation and the evaluation of the simulation model have provided information which may be used to develop management strategies for savanna woodlands. For any management to be meaningful, however, it must be directed to the attainment of clearly defined goals.

There are a number of potential goals which may be aimed for - sustained yield of a particular resource, or the development of a closed woodland - each of which necessitate their own management strategies. These goals in turn depend on the requirements of the local communities or the goals of the authorities.

The model in particular has emphasized that the development of the savanna is a result of long term influence of environmental factors on the vegetation. This was to some degree supported by the field observations which showed that different management practices had resulted in structural differences (particularly growth forms and species) of the vegetation.

In practice, however, vegetation management is restricted to only a few options. These include fire management, management of grazing animals and some silvicultural activities such as

inter-planting or thinning. Since the potential goals are manifold, the paragraphs below discuss the potential impact of these management activities on the vegetation.

29.1 Fire

While the effects of fire have been dealt with in some detail during the evaluation of the model, a few points need to be highlighted.

The model assumes that the effect of fire is primarily manifested in its intensity, and the ability of the vegetation to withstand the effects of a burn. While fire frequency plays an important role, its effect on the vegetation can be measured in terms of cumulative intensity.

In the event that a vegetation is able to survive one fire but is unable to recuperate to pre-fire levels before the next burn, it will deteriorate. If the vegetation is unable to withstand the effects of a burn, it will also deteriorate. The same principle applies to the effect of cumulative fire intensity. While plants may withstand a number of fires in a row, they may be killed in the long term.

This approach to the effect of fire suggests that its impact may be regulated by modifying fire intensity and cumulative intensity. Depending on the vegetation to be promoted this may

be done by preventing fires, scheduling burns, or by manipulating the fuel load.

If fire is totally excluded flammable material will build up. The eventual burning of such an accumulated fuel load would result in a very high fire intensity and a resulting high level of damage. In practice, the total exclusion of fire is difficult to attain in Namibia due to the large areas involved, and the limited resources available.

The implementation of a burning regime is perhaps the most difficult management technique to implement, since it must consider the time of burn as well as the frequency. While the model indicates that consistent early burning will promote the development of the savanna towards woodland this effect is modified by the cumulative fire intensity.

If fires are too frequent for the current vegetation to absorb or if the fuel accumulates at such a rate that fires are very intense despite the scheduling, vegetation development will be towards grassland. Fuel load development may be manipulated by the removal of some material.

Excessive fuel build-up may therefore be prevented in a number of ways:

- periodic burning may be implemented to reduce the amount of accumulated fuel, although this consideration must be incorporated in the burning regime as a whole;
- a burning regime may be implemented which promotes the establishment of a vegetation which produces little fuel; or
- fuel may be physically removed by introducing grazing or even by removing flammable material by hand, for instance through controlled collection of fire wood or thatch.

In general terms, the effect of frequent fires on the vegetation is such that it may enhance the conditions for further burning, i.e. by promoting grassland. Simultaneously, however, repeated burning will encourage the development of a vegetation that may withstand the effect of fires.

29.2 Herbivory

The field study indicated that differences in grazing management promotes different vegetation types. (For instance, a higher grazing pressure on farm Rooidag coincided with a taller woody vegetation component than did the absence of grazing in the communal area.) This is primarily due to two effects.

As indicated above, the removal of grass fuels modifies the effect of fire by reducing the fuel load and may therefore lower fire intensity. In addition the smaller amounts of grass

fuels reduce the likelihood of fire, since these fuels are more flammable.

On the other hand, a reduction in the herbaceous cover also enhances the infiltration of water to lower lying soil layers thus promoting the growth of the woody vegetation component. This effect of course depends on the intensity of grazing since low intensity grazing may encourage the formation of tillers on perennial grass plants and therefore promotes the herbaceous vegetation.

Very high herbivore density may also affect the regeneration of woody plants adversely. Once the herbaceous cover has been reduced herbivores will make use of regenerative material. The literature review indicated, for instance, that *P. angolensis* seedlings would be eaten by Kudu (von Breitenbach 1973).

29.3 Silviculture

Although the implementation of silvicultural practices has not been discussed separately, the results of the model as well as some previous experiences in the study area permit certain speculation in this regard.

The model indicates that a higher growth rate in the savanna significantly reduces the time that the vegetation requires to attain woodland status. Depending on the goals to be achieved

the growth of specific trees might be enhanced by the removal of competing herbaceous material.

Practices such as inter-planting have a limited possibility of success. An attempt to establish an arboretum in the vicinity of the study area showed that seedlings required regular watering. Even if this may had been financially viable in the long term the watered plants represented the only green plant material in the vicinity, especially during the dry season, and were severely damaged by small antilope and ants (*pers. obs.*).

On the other hand, it may be possible to encourage the development of the woody vegetation by applying seed directly. Such practices must, however, be investigated further.

Thinning of the woody vegetation would cause a slower canopy closure rate and therefore retard the progression of the savanna towards woodland status. The type of thinning which is most applicable must be determined. Due to the low number of trees found in the study area it is unlikely that their removal will have significant impact on the remaining woody vegetation.

It must also be considered that many of the plants may coppice, and that the thinning may cause the exact opposite effect, i.e. cause more rapid canopy closure. This may of course be intentionally done, but the species composition in the area will determine the success of this approach.

30. *Pterocarpus angolensis* MANAGEMENT

In general the management of *P. angolensis* is concerned with the management of competitors. This may be achieved either by physically removing competing plants or by implementing a burning regime which favours *P. angolensis*.

The techniques to be implemented will be dependent on the other woody species in the area, their growth rates and their ecology. For instance, if other species are also fire tolerant a higher fire frequency may need to be implemented which might also disadvantage *P. angolensis* to a degree, but provide the tree with an competitive advantage overall.

The model shows that management of *P. angolensis* may be achieved through woodland management, since establishment, reproduction and survival of the species are closely linked to the development of the savanna vegetation.

Vegetation management should strive to create conditions which permit the species to advance through its developmental stages. Such conditions are not necessarily uniform throughout the different stages, and the status of the species needs to be closely monitored. The following paragraphs therefore summarise the conditions which would be most favourable for the individual stages.

30.1 Seed Production and Germination

For maximum seed production the parent trees must be subject to very low levels of competition from the surrounding vegetation.

According to the model favourable conditions may be achieved by artificial thinning of the vegetation or by implementing a fire regime which would disadvantage other woody plants. A burning schedule must, however, be determined with reference to the other woody species which occur in the area since they determine the degree of competition, the rate of fuel build up and the fire hardiness of the competing vegetation as a whole. Care must be taken not to cause mortality of the parent trees.

Seed germination in itself benefits from moderate fires since they enhance germination. In terms of resource management this would mean that increasing the number of cooler fires through early season burning should assist in the regeneration of *P. angolensis* by stimulating germination. On the other hand, late burns will prolong the competitive advantage of seed trees, and therefore produce larger quantities of seed as a whole.

Apart from implementing burning regimes, sections of the woodland area could be made available for shifting cultivation. Once the areas are abandoned there will be few competing plants, and transplanted seedlings may have a better possibility of survival. This option must, however, be investigated further.

30.2 Suffrutex Development

Since the establishment of seedlings is primarily determined by rainfall, management needs to focus on the survival and development of suffrutex plants. The susceptibility of seedlings to herbivore damage must, however, be kept in mind during the planning of management strategies.

While frequent cool fires promote germination, such fire frequencies retard development of suffrutex plants. According to von Breitenbach (1973) the suffrutex behaviour permits the plant to develop a large enough root system to support a permanent shoot. At the same time the suffrutex is less prone to fire damage, although Vermeulen (1990) indicates that annual burning will retard its development.

Excessive competition will also hamper the development of plants through the suffrutex stage (Boaler and Schiwale 1966).

Suffrutex development will be enhanced under conditions of low competition with the surrounding vegetation and low or moderate fire frequency.

30.3 Tree Development and Survival

Once plants emerge from the suffrutex stage to develop their permanent shoot they benefits from their higher fire resistance (Vermeulen 1990). However, this resistance may be overcome by frequent fires, as shown by the lesions seen on trees in the field.

31. EXPLOITATION

The effect of exploitation needs to be considered carefully in the light of the restricted knowledge. Since the model only provides tentative guide-lines towards management, no concrete rules can be set according to which exploitation should take place.

Graham (1983) provides the following considerations, however.

- A maximum tree size for remaining trees in a stand must be determined, and must serve as goal for exploitation management and control.

- A cutting cycle must be determined, depending on the growth of the stand.

(Growth must not only consider individual tree growth, but the growth and development of the stand as a whole.)

- Tree selection should be based on vigour, form or health. This is supported by Seydack (*pers. com.* 1994)

In addition, the recommendations of Gover (1972) should be noted, that an effort should be made to retain both the overall structure of the woodland, and also to create conditions suitable for regeneration.

32. RECOMMENDATIONS

The evaluation of the model highlighted the need for more concrete information. Initial activities must therefore concentrate on research. The following is recommended:

- to determine methods for sowing *P. angolensis* in the field so that artificial regeneration is possible.

- to determine the fire frequencies which provide the seedlings, suffrutex plants and trees with a competitive advantage over the remaining woody vegetation.

- to determine a method suitable for aging individual *P. angolensis* plants.

- to determine appropriate thinning techniques to reduce the amount of competition.

- to determine signs which indicate that a tree is dying, so that a portion of the population may be removed without affecting the survival of the population as a whole.

- to determine the natural, site specific mortality rates.

- to determine the ability of coppice material to survive, so that it may be incorporated in a management plan.

- to determine growth rates.

33. CONCLUSION

At this time there is little or no active management of the savanna woodlands in northern Namibia, although large areas of these woodlands are incorporated in conservation areas. While the authorities have realized that fires play an important role in the maintenance and development of this vegetation, fire management is restricted to attempts to exclude fires from the areas. However, due to limited resources and limited local knowledge this form of management is not effective.

The literature reviews, the field survey and the model attempted to provide insight into the management requirements of *P. angolensis* within the savanna woodlands. The literature provided the context in which *P. angolensis* must be seen, and the basic information for the compilation of the simulation model. The field survey, in turn, highlighted the effect of grazing practices on savanna development.

The rule based model on the other hand indicated a number of places where the available information is insufficient for the development of management strategies.

This study therefore serves as a guide-line to management planners to indicate what needs to be considered if the vegetation is to be manipulated. The study also serves to show what additional research is required to ensure that *Pterocarpus*

angolensis may be utilized on an ecologically sound and sustainable basis.

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APPENDIXES

1 EVALUATION OF ALTERNATIVE STUDY AREAS

1.1 Bushmanland

The area referred to as Bushmanland here is located approximately between 19o17'E, 19o5'S and 19o15'E,19o17'S, and includes the farms Rooidag (1001) and Talitha (1006) and adjoining sections of the formerly communal area of the Tsumkwe district.

Representativeness of the Area:

- Studies previously carried out in Kavango (Geldenhuys 1977) and western Caprivi (von Breitenbach 1968), and personal observations in western Bushmanland, indicated that the species occurring in the proposed area represent those found in the other savanna woodland areas of Namibia.
- Although insufficient information was available on the soils of Namibia, the available geological maps indicated little variation in soil types for Namibia's savanna woodlandareas.
- According to the available rainfall maps (Amakali 1992), precipitation in the proposed area is representative of the region.

Human influence and Land Use:

- In view of the low population density in the communal section of the area illegal cutting was restricted to only a few localities within that area.
- Pastoral farming was the predominant form of land use in the extreme western parts of the area. The extent of this form of land use was restricted, however, due to the occurrence of 'Gifblaar' (*Dichapetalum spinosum*) a poisonous plant which inflict heavy stock losses.

Available Information on the Area:

- A vegetation survey of Bushmanland was conducted in 1982. Although the methods used in the survey were not available some conclusions may be drawn on vegetation development nevertheless.
- Some 1988/89 LandSat TM imagery is available on the western section of the area, 1992 SPOT XS images are available for the whole north eastern parts of the country.
- Research on the coppicing behaviour of P. angolensis is currently on-going in the area, and results may already be available.
- The Directorate of Forestry is currently engaged in mapping the vegetation of the entire northern parts of the country.
- The farmers in the area were prepared to provide information concerning grazing on their properties.

- Past exploitation of Kiaat in the area had been documented.
- In view of the implications that wild fires hold for the status of grazing land on the commercial farms, some farmers have kept records on the fire history of their farms. This information may be available for the purposes of the study.

Other Advantages:
- A number of organisations are currently conducting studies in Bushmanland, although most of these are concentrated on the more densely populated eastern parts. Communication with the organisations will provide valuable opportunities to share information.
- The author has previous experience of the area.

Disadvantages:
- The incidence of fire in the eastern sections has not been documented although this type of information is lacking for all other areas that were considered.

1.2 Okavango

The Okavango region supports a considerable portion of the drysavanna woodlands of Namibia. The following considerations are relevant:

Representativeness of the Area:
- The considerations concerning the soils and most of the vegetation composition of Kavango coincide with those for the Bushmanland area.

Human influence and Land Use:
- Few records concerning the history of land use are available for Kavango, particularly with regard to the exploitation of *P. angolensis*
- The southern sections of the region are currently under development for commercial farming purposes. Some records on land use in this area may therefore be available from the Department of Agriculture.
- The high population density especially in the northern parts of the region, coupled with a thriving market for traditional woodwork, has resulted in extensive unrecorded exploitation.
- Domestic stock does not play as important a role in the communal farming sector as it does in other areas of the country.

Fire History of the Area:
- The southern parts of Kavango borders on the same area as the potential study area in Bushmanland, and the same considerations are applicable.

Potential Disadvantages:
- While the occurrence of illicit harvesting is presumed to be concentrated in the northern parts of the region, the

difficult access reduces the suitability of the less densely populated south considerably.

1.3 Caprivi

The Caprivi region was previously identified as a pilot area for forestry development in Namibia since this area supports a valuable portion of the country's forestry resource.

The following should be noted:

Representativeness of the Area:

- The available geological maps of Namibia indicate that the soils in Caprivi are similar to those of the whole of north eastern Namibia.
- From available rainfall maps it is evident that the Caprivi region receives an annual rainfall markedly higher than any other area in Namibia. This seems to be one of the primary causes for the high value of its forest resource.

Human influence and Land Use:

- The western parts of the Caprivi region were declared protected (game reserve) by the conservation authorities just before the area was occupied by the South African armed forces during the war for Namibia's independence. Access to the area was restricted (if not hazardous) and this limited land use.

Fire History:

- Discussions with forestry officials stationed in the Caprivi have shown that the region is subject to annual burning.

Available Information:

- A number of studies have been carried out on the vegetation in Caprivi and a management plan was compiled during the late 1960s.
- Exploitation of Kiaat has been documented by the Lutala Sawmill.

Possible Disadvantages:

- The floodplain of the Zambezi extends well into the eastern parts of the region, causing differences in soil conditions.
- The long distances that need to be travelled to reach the area for field work would more than double the cost of transport.
- Few records are available on land use.
- Most exploitation was restricted to the eastern, moist sections of Caprivi due to the war situation.
- Since rainfall has been identified as one of the key factors in the dry savanna woodlands the atypical precipitation makes the area less representative of the biome within Namibia.

2 SOME PRINCIPLES OF REMOTE SENSING

Remote sensors such as the French SPOT satellite record electromagnetic radiation reflected or emitted from the earth's surface. These recordings are not collected over the entire electromagnetic spectrum, but rather in a series of bands, each of which may provide information concerning certain aspects of a feature. (See also Richardson and Wiegand, 1977, who relate various vegetation density indicators to spectral reflectance data of the Landsat system)

The table below (Table A.1) provides a summary of the SPOT XS wave bands and their uses relevant to this study:

Wave Band	Spectral Range (µm)	Use
1	0.50 - 0.59	Measurement of green reflectance of green vegetation
2	0.61 - 0.68	Useful for discriminating between plant species and to delineate soil boundaries
3	0.79 - 0.89	Especially responsive to the amount of vegetation biomass, and can be used for crop identification.

Table A.1: SPOT XS wave bands and their utilities in the stratification of vegetation into possible units. (Source: ERDAS Field Guide 1982, p.24)

Most visible light (0.4µm to 0.7µm) is absorbed by photosynthetic pigments, while near infra-red waves (0.7µm to 1.3µm) are reflected by the interface between cell walls and inter-cellular air spaces (Barbour, Burk and Pitts 1987, p.222). A further wave band, not monitored by SPOT XS, covers 1.5µm to 2.5µm (shortwave infrared) and is absorbed by leaf water (Barbour, Burk and Pitts 1987).

The primary differences in the reflectance of different species are therefore dependent on the morphological features of their leaves which affects both the pigment content and physical structure. Major difference in leaf reflectance are dependent on leaf thickness. (Curran 1985, p.24, Gates *et al.* 1965)

In addition, the geometry of the vegetation canopy will determine the amount of shadow recorded by the sensor (Curran 1985, p.24)., as well as the amount of leaf area exposed The physiological state of the plant will determine the amount of pigmentation and water in a leaf.

While it is possible to classify homogeneous standing crops on agricultural lands by virtue of a spectral signature, natural vegetation is more difficult to classify due to greater species heterogeneity (Barbour, Burk and Pitts 1987). Curran (1985, p.29), however, points out that the reflectance of a rough tree canopy may be distinguished from a smoother grassland canopy.

Further assistance is given by the season in which the image was recorded (Jarman *et al.* 1983). The image used in this study was taken towards the end of the rainy season.

Although no field check could be carried out in the year of origin of the image, a visit to the area during the same season a year later showed that the vegetation on the dune ridges and the grasses had already started to turn brown. The *Acacias* in the streets had remained green until later.

3 MATERIALS

3.1 Details of the satellite image used during mapping

Sensor	SPOT XS
Nodes	111-388 111-389
Date	21.05.1992
Ground Resolution	20m

3.2 Details of the satellite image map

Projection	Traverse Mercator
Central Meridian	19 E
Latitude of Origin	22 S
False Northing	0
False Easting	0
Scale	1 : 50,000
Spectral Bands (RGB)	3 2 1
Processing	Processing before printing was carried out by SSC Satellitbild in Sweden. Details were not provided with the images

3.3 Details of topographic maps used

Topographic Maps:	1919 AA 1919 AC
Scale	1 : 50,000
Projection	Transverse Mercator
Central Meridian	19 E
Source	Aerial Survey Job 723/1973

3.4 Methods for Soil Analysis

The soil samples were analysed by the Agricultural Soil Laboratory of the department of Agriculture, as part of an Agro-Ecological Zoning project. This significantly reduced costs.

The following methods were used:

Phosphorus	- Ohlsen Method - Extractant NaHCO3 - Absorbance measured spectro-photometrically at 882nm
Extractable and Water soluble cations	- Extractant Ammonium Acetate (1mol/dm3, pH 7) - Calcium and magnesium absorbance measured with Atomic Absorption Spectrometer - Potassium and sodium atomic emission measured with Atomic Absorption Spectrometer
pH	- 1:2.5 soil / 1mol/dm3 potassium chloride ratio suspension on a mass base
Texture	- Dispersion with Calgon - Measurement with hydrometer - USDA Classification used